# NAVAL POSTGRADUATE SCHOOL
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# THESIS

**DESIGN AND IMPLEMENTATION OF REAL-TIME, DEPLOYABLE THREE DIMENSIONAL SHIPHANDLING TRAINING SIMULATOR**

by

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With a shrinking defense budget, surface ship underway bridge watchstander training opportunities have been reduced significantly. Actual underway watchstanding time on the bridge of a ship is crucial to the development of shiphandling skills and most importantly development of all shiphandlers situational awareness ("seaman's eye"). Shiphandling, coupled with a true appreciation and understanding of the forces which act on ships are necessary skills which all Surface Warfare Officers must develop.

One long standing solution involves the use of full-scale shiphandling training simulators. Such facilities provide a very realistic view of the world as seen from the bridge of an actual vessel; nonetheless, there are currently only two such facilities available to the Navy. Additionlly, the curriculum offered at these facilities is only tailored for use by more experienced senior officers, moreover, due to their location, tremendous out of area travel expenses are incurred, further limiting the access of potentially qualified users. These circumstances invariably result in the only opportunity for junior officer shiphandling training is when at sea.

One solution to alleviate this shortfall, is to develop a low cost, real-time, three dimensional portable shiphandling simulator, suitable for installation aboard U.S. Navy ships. Given the level of current technology, this is easily attainable. An extensive usability study validated the design of the prototype.

The method taken was to design such a system which makes use of a single, Silicon Graphics Inc. Reality Engine series computer (as host), for the high resolution graphics needed in producing an accurate rendition of a stereoscopic virtual database and to achieve the goal of transportability. The system makes use of C++ Object Oriented Programming concepts utilizing the IRIS Performer application programming interface (API) to optimize high-speed rendering for the virtual world environment in which the ship(s) can navigate. Network implementation was achieved utilizing existing data structures in the NPSNET-IV battlefield simulation program.

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# DESIGN AND IMPLEMENTATION OF REAL-TIME, DEPLOYABLE THREE-DIMENSIONAL SHIPHANDLING TRAINING SIMULATOR

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One solution involves the use of full-scale shiphandling training simulators. Such facilities provide a very realistic view of the world as seen from the bridge of an actual vessel; nonetheless, there are currently only two such facilities available to the Navy. Additionally, the curriculum offered at these facilities is only tailored for use by more experienced senior officers, in addition, due to their location, huge out of area travel expenses are incurred, further limiting the access of potentially qualified users. These circumstances invariably result in the only opportunity for junior officer shiphandling training is when at sea.

Our solution to alleviate this shortfall is to develop a low-cost, real-time, three dimensional portable shiphandling simulator, suitable for installation aboard U.S. Navy ships. Given the level of current technology, this is easily attainable. An extensive usability study validated the design of the prototype.

The method taken was to design such a system which makes use of a single, Silicon Graphics Inc. Reality Engine series computer (as host), for the high resolution graphics needed in producing an accurate rendition of a stereoscopic virtual database and to achieve the goal of transportability. The system makes use of C++ Object Oriented Programming concepts utilizing the IRIS Performer application programming interface (API) to optimize high-speed rendering for the virtual world environment in which the ship(s) will navigate. Network implementation was achieved utilizing existing data structures in the NPSNET IV battlefield simulation program.

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# I. INTRODUCTION

## A. BACKGROUND

### 1. Development of the Seaman's Eye

With the shrinking defense budget, shipboard underway bridge watchstander training is becoming less available. Actual underway watchstanding time on the bridge is crucial to the development of shiphandling skills and most importantly in developing what is referred to in the U.S. Navy's surface warfare community as the "seaman's eye". Shiphandling, coupled with a true appreciation and understanding of the forces which act on ones vessel is a necessary which all surface warfare officers must develop. Ones ability to safely control the movement of a ship in a myriad of different maritime situations is of paramount importance for a number of reasons -- with the principle one being an emphasis on safety.

On most U.S. naval vessels, underway bridge team watchbills or scheduled times that conning officers are assigned to the bridge watch team, are composed principally of an inexperience, first-tour junior officer (usually assigned as conning officer) and at best, a second-tour junior officer with perhaps slightly more underway experienced on the bridge -- assigned as Officer Of the Deck (OOD). Such inexperienced watchstanders have been involved in some of the Navy's most noted collisions at sea (e.g. HMS Melbourne - U.S.S. Evans, U.S.S. Kennedy - U.S.S. Belknap). These costly accidents usually result in millions of dollars in damage to our nation's vital maritime defense assets, countless lost work days and in some cases tragic loss of life. Further examination reveals one common element or factor that stands out among all others -- that being lack of sufficient quality training for those junior officers placed in such vital positions of responsibility. The question: how can quality situational awareness training (development of the "seaman's eye") and competent shiphandling skills associated with underway bridge watchstanding be learned and developed given an environment of limited afloat assets and reduced underway operations?

### 2. Current Solutions to an Age Old Problem

In recent years, naval leadership have initiated a number of creative strategies to aid in alleviating this training shortfall. One such strategy has been to crossdeck (or temporarily transfer) junior officer watchstanders to other units either preparing to deploy or involved in at-sea operations, to facilitate their gaining some of the necessary underway bridge watchstanding time which is crucial to the development of these invaluable shiphandling skills. A problem frequently encountered with this strategy, has been that the host ship(s) sponsoring the training must likewise provide the same shiphandling training opportunities for its own junior officer watchstanders. When faced with limited underway time, as well as significantly reduced opportunities to conduct such training, this can and often does become quite a juggling act. Thus oftentimes the transferred junior officer(s) may reap only limited benefit from the training opportunity at significant monetary cost.

Another strategy involves the use of full-scale shiphandling training simulators which make use of three dimensional computer graphics. These full scale facilities provide a very realistic view of the world as seen through the bridge windows. The use of simulators makes possible an infinite variety of potential scenarios involving shiphandling, which include getting underway from and mooring to piers in all manner of environmental challenges; formation steaming; underway replenishment; piloting in narrow channels; and transits through restricted waters and crowded shipping lanes. Currently, there are only two shiphandling training simulators available to the Navy operated by Marine Safety International (MSI), a private contractor with full-scale shore based facilities located in San Diego, CA and Newport, RI [USN94].

Although tremendously capable and technically sound training vehicles, two key problems arise with their use. The first is the location of these facilities. The second concerns the fact that the contractor for is tasked to provide these services only for more senior personnel such as prospective afloat Department Heads, Executive Officers (PXO), prospective Commanding Officers (PCO), reserve midgrade officers and major command prospective Commanding Officers. The curriculum provided focuses on honing the "seaman's eye" of the prospective COs and XOs, sharpening skills already developed at sea [USN89]. Table 1 provides a breakdown of the current course attendees for whom services are currently being provided for. This policy raises two interesting questions. First, why are current simulator services only being offered to more experienced senior watchstanders (i.e. PDHs, PXOs, PCOs, etc.) of whom many spend far less time standing underway bridge watches than their more junior subordinates? When the question was posed to both Navy and MSI officials as to the reason a junior officer level training program had not been developed to address those shortfalls in shiphandling training obviously identified in the Navy's historical safety data on collision mishaps? The response was simply that it was believed that these personnel did not possess the level of knowledge or shipboard experience to understand the actual workings of a ship at sea.

| Level | Course | Hours |
|---|---|---|
| Intermediate | Department Head | 16 |
| Advanced | Surface PCO/PXO | 16 |
| Advanced | Aviation PCO/PXO | 32 |
| Intermediate | Reserve Midgrade | 16 |
| Advanced | Major Command PCO | 12 |

**Table 1: Current Target Group of Simulator Training Services**

The second problem associated with these facilities addresses their location. Currently both facilities are only located in two of the Navy's homeports (i.e. Newport, RI and San Diego, CA). Ships homeported out of the immediate area of both complexes, are required to expend often limited and increasingly scarce training funds generally dedicated to local training requirements -- toward defraying long distance commuting or out of area cost for travel, lodging, and per diem associated with sending personnel to these training complexes.

We believe that what is needed to provide greater access to realistic training scenarios such as those provided in the full-scale mock-ups, is a transportable or deployable version of a shiphandling simulator that could either be installed aboard a deploying/ operational afloat unit or located within the immediate proximity (i.e. pier side) of the ship when inport. Given today's computer technology, such systems could provide a number of very capable features and have nearly if not better "fidelity" than the full-scale mock-ups at a fraction of the cost - while providing far more increased access. These systems would significantly increase the availability of much needed training, and thus further aid in the development and enhancement of the situational awareness needed in developing that all important "seaman's eye" so critically required in today's junior officer bridge watchstanders.

Additionally, such a highly mobile, low cost, and easily expandable training system can easily be developed using existing graphics hardware to provide real time three dimensional training scenarios and a host of different ship types tailored to the desires of the command(s) as required. Required software can be written to simulate the movement of a vessel(s) through the waters possessing the same if not similar environmental forces that influence or impact on the behavior of today's ships in the real world. Virtual terrain databases mimicking the geography of the many of the harbors or ports-of-call frequently visited by U.S. naval vessels could be developed, utilizing existing modeling tools (i.e. MultiGen, AutoCad, etc.) to further enhance realization. To date, no such device of this scale has been developed within the realm of the naval service which is targeted toward those surface warfare officer's greatly in need of such training -- today's young surface warfare officer.

### 3. Taking the System One Step Further with NPSNET IV

An additional feature of this training vehicle would be to provide for mutual interaction in a three dimensional, multi-ship virtual operational environment by means of real-time network interaction. Such a robust, high-performance and efficient implementation could be made possible through the use of the Distributed Interactive

Simulation (DIS) protocol suite like NPSNET-IV, being implemented at the Naval Postgraduate School [ZESW93].

DIS 2.0.4, is the latest version of this emerging international standard for distributed simulation. The Naval Postgraduate School (NPS) has developed a network harness. The harness is a software architecture designed to take advantage of the multiple processor machines available in today‘s computer graphics industry.

NPSNET IV is the most current version of the evolving NPSNET simulation system. The architecture uses BSD 4.3 socket-based interprocess communication (IPC) to provide a clear, easily used, and well-documented network interface. NPSNET IV, the simulation application, is tailored with efficient mechanisms to map DIS data to NPSNET data structures. The DIS network library that was developed through previous research at NPS resulted in a network harnesss for DIS applications. NPSNET further provides a three dimensional virtual world (VW) on Silicon Graphics workstations. The DIS protocol allows real-time, three dimensional computer simulation systems (e.g. NPSNET) to interact with other independently developed simulations (e.g. Virtual Cockpit, World Reference Model) via communication networks [ZESW93].

## B. MOTIVATION

### 1. In The Face of Shrinking Resources

The pipeline for individual shiphandling training has for many years included simulator training either at Newport, RI or San Diego, CA. Upon reporting to his/her ship, the junior officer begins an established bridge watch team training program promulgated under the direction of the Commanding Officer to further refine the individual’s basic shiphandling skills and to develop the individuals skills in handling his/her assigned ship type. This training was supported by numerous fleet and individual ship exercises designed to present the challenges posed by differences in ship types, ship interactions, and operating environments. This bridge watch team training consumed the majority of the inter-deployment training time and money.

Recently, three direct actions have severely impacted the CO's ability to meet the normal challenges of at-sea operations and to establish a meaningful training program which addresses the diverse skill levels of personnel assigned. One of these has been the downsizing of the Navy with the concomitant loss of sea going assets to train crews at sea. As ships become fewer in number, so have the opportunities for fleet interaction, thus diminishing training opportunities. Another action caused by the current downsizing trend has been the rapid decommissioning of many fleet assets, to include entire ship classes such as the Knox (FF-1052) class Frigates, Adams (DDG-2) class Destroyers, Leahy/Belknap class Cruisers and the Newport (LST-1170) Tank Landing Ships. They are succeeded by the Ticonderoga (CG-47) class Cruisers, the Arleigh-Burke (DDG-51) class Destroyers, and the Whidbey Island (LSD-41) class Landing Ship Dock Amphibious Assault Ships, all of which differ significantly in shiphandling characteristics and require additional or specialized in their handling. Overall, this additional training requirement has lead to a significant disruption in the normal methodology and timeline for training young surface warfare officers slated for future assignment in these new highly technical ship classes. In fact, this specialized training has thus been accelerated, simply because there are neither the hulls nor the opportunities to permit gradual accession into the normal underway bridge watch team rotation scheme.

A third and final action that has and will continue to impact current shipboard shiphandling training programs is the recent accelerated assignment of female officers to an even larger number of afloat vessels. As their numbers increase, there will be increased pressure to afford them every opportunity to participate on an equal playing field with their male counterparts. Thus given the fact that they possess little or no exposure to shipboard life, coupled with a lack of recent tangible shiphandling experience, they perhaps will create the greatest challenge to current training efforts and philosophies.

It is increasingly apparent that these circumstances have been a direct result of the budget reduction process, requiring Fleet Commanders to quickly find alternative training methods to ensure continued safe operation of the remaining afloat assets. It is imperative that the safe operation of these afloat assets not be compromised, while at the same time ensuring smooth integration of its inexperienced officers into effective underway watch teams. For these reasons, it is now increasingly important to obtain shiphandling simulator services/facilities for our Surface Fleet unlike ever before.

### 2. A Question of Safety

Over the past twenty to twenty-five years, the concern for safe operations at sea has increasingly become an issue of paramount importance to both commercial interests as well as the United States Navy. For example, in the commercial market, there have been a number of very costly maritime mishaps resulting in millions of dollars in lost revenues from ever increasing repair and cleanup cost. An additional key concern driving this new found awareness in maritime safety has been the tremendous environmental damage resulting from a number of these mishaps. Most notably was the case of the tanker Exxon Valdez, which under the command of Captain Joseph Hazelwood, ran aground on March 24, 1989, while departing Alaska's Prince William Sound. The environmental destruction caused by this mishap was so devastating and costly to clean up that to date its cost to government agencies was reported as being over $125.2 million dollars for cleanup, $12.3 million for damage assessment, and $1.1 million for other cost resulting from the spill [GAO90].

As in the case of the commercial maritime industry, the United States Navy also has experienced its share of maritime mishaps. Most importantly, each mishap has resulted in the loss or damage to two of our nation's most precious assets -- its ships and its highly skilled and trained young sailors. Such losses have resulted in countless lost days due to lengthy and costly repair periods. Needless to say, such repair efforts often require extensive dry-docking periods rendering vessels unavailable asset(s) for use in our nations' defense. In the case of personnel, operational units are imminently faced with the reassignment and/or permanent loss of injured personnel, thus resulting in their replacement by less experienced sailors relatively new to rigorous seagoing assignments.

Further review and analysis of mishap data provided by the Naval Safety Center in Norfolk, Virginia, revealed that in a large number of these mishaps reported, nearly 95 percent were clearly avoidable if the personnel involved had recognized the situation and taken timely measures to prevent or reduce the impact of the collision.

The maritime mishap data currently being collected by the Navy regarding collisions-at-sea covers the period of the past twenty to twenty-five years. This data clearly reveals some very compelling information regarding the overall safety record of it's afloat units. Due to the enormous quantity of data obtained, we have chosen to focus our efforts toward analyzing only the data covered by the period from 01 January 1980 through 14 September 1994.

The results of this analysis reveals several key facts and conclusions. Portions of the data are presented in a series of tables to allow the reader an opportunity for examination and review. Our goal is simply to review the data and identify possible trends or shortfalls in previous training efforts where possible. Later in this report we will offer possible suggestions as to how our multi-shipboard training simulator can best be employed to aid in improving the seaman's eye and to further aid in the development of those critical shiphandling skills so important for tomorrow's surface warfare warriors.

Table 2, provides a comparison of the number of mishaps occurring in afloat units assigned to both Type Commanders of the Atlantic (LANT) and Pacific (PAC) Fleet. The data illustrates that there were consistently more collision mishaps occurring among ships assigned at to the Atlantic fleet than those assigned Pacific fleet. In fact, during the individual two year reporting periods, LANT fleet vessels were nearly one and a half times more likely to be involved in a collision mishap than those in PAC Fleet. The reasons for this disparity is not known, however, from the authors' experience, there may have been certain geopolitical events which may justify or have contributed to the larger number(s) of mishaps occurring among LANT fleet vessels. Only in year groups 83 - 85 and 92 - 94 were the numbers below the 1:1.5 factor ratio.

| TYCOMs | 80 - 82 | 83 - 85 | 86 - 88 | 89 - 91 | 92 - 94 | Totals |
|---|---|---|---|---|---|---|
| **LANT** | 86 (62.7%) | 98 (58.3%) | 52 (61.2%) | 75 (68.2%) | 21 (52.5%) | 332 (61.5%) |
| **PAC** | 51 (37.3%) | 70 (41.6%) | 33 (38.8%) | 35 (31.8%) | 19 (47.5%) | 208 (38.5%) |
| **Totals** | 137 (25.4%) | 168 (16.7%) | 85 (22.4%) | 110 (36.4%) | 40 (5.0%) | 540 (23.0%) |

**Table 2: Comparison of Mishaps by Type Commander**

When analyzing the data as a whole for the entire period between January 1, 1980 through September 14, 1994, the combined total number of collision mishaps reported was 540 (See Table 3 below). Of these mishaps, 61.41 percent involved ships of the Atlantic Fleet, while 38.51 percent involved Pacific Fleet vessels. These numbers remain consistent with the figures compiled for each of the two year reporting periods illustrated in Table 2.

In Table 3, we examined the frequency of collision mishaps as they applied to specific ship types. Additionally, there appeared to be some definite trends regarding the particular ship types frequently identified as being assigned to the Cruiser-Destroyer (CRUDES) warfare mission area. The data indicated some very compelling and surprising information. The actual number of collisions were far greater among frigates than in other afloat surface unit types in this warfare area by as much as 98.1% for battleships, 81.3% for carriers, 82.2% for cruisers, and 27.1% for destroyers.

Traditionally, the more junior officers have been assigned to mostly frigates and destroyers of which tended to suffer the greatest number of collision mishaps. Additionally, when considering the role or warfare mission area assigned to these two particular ship types (i.e. ASW) and their given hydrodynamic characteristics -- which make for more highly maneuverable, there perhaps is a real need for the assigned surface warfare officers to develop their shiphandling and situational awareness to an even higher level of proficiency than those assigned to other ship types of the CRUDES mission area. A similar trend or condition was also noticed when comparing large and small ship amphibious warfare types. The frequency of collisions in the medium ship types (i.e LSTs, LSDs, LPDs) were found to be 52.3% greater than their larger counterparts (i.e. LHAs, LHDs, LPHs).

Additionally, the reader will note in Table 3, that the number of mishaps involving submariners is quite high in comparison to those involving afloat units. Understand, that the focus of our research is principally aimed at the problems being experienced among those officers which make up the Surface Warfare speciality. However, it is abundantly clear that the submarine units present an entirely different challenge for its young officers, simply inherent with the vastly different hydrodynamic characteristics of that particular ship type. What the data indicates, is that submarines are on the surface, they are more than likely to experience a collision.

| SHIP TYPE | 80 - 82 | 83 - 85 | 86 -88 | 89 - 91 | 92 - 94 | Totals |
|---|---|---|---|---|---|---|
| Battleships | 0 | 1 | 0 | 1 | 0 | 2 |
| Carriers | 7 | 7 | 4 | 2 | 0 | 20 |
| Cruisers | 2 | 9 | 1 | 5 | 2 | 19 |
| Destroyers | 22 | 20 | 10 | 20 | 6 | 78 |
| Frigates | 15 | 39 | 15 | 28 | 10 | 107 |
| Patrol Combatants | 2 | 0 | 1 | 3 | 0 | 6 |
| Amphib. Warfare (LG) | 10 | 6 | 4 | 1 | 3 | 34 |
| Amphib. Warfare (MED) | 20 | 16 | 7 | 15 | 7 | 65 |
| Submarines | 32 | 41 | 27 | 12 | 2 | 124 |
| Assist/Repair | 11 | 10 | 10 | 7 | 3 | 41 |
| Underway Replenish | 12 | 12 | 5 | 13 | 4 | 46 |
| Mine Warfare | 4 | 7 | 1 | 3 | 3 | 18 |

**Table 3: Frequency of Collisions by Ship Class**

From this data alone, a number of questions arise.

- Could the mission area of these smaller ship types coupled with the assignment of less experience junior officers be contributing factors to their higher incidents of collision?
- Is there a lack of emphasis in these commands for developing proper shiphandling skills than that found in both the cruiser, battleship, carrier, and large amphibious warfare ship types?
- Could a greater integration of training simulators be a viable and cost effective training vehicle to assist in the development of those shiphandling skills and situational awareness (seaman's eye) currently found to be lacking in today's junior surface warfare officers?
- Is there sufficient emphasis being placed on safety prior to and frequently reemphasized during each evolution and underway period?

The answers to these questions are not at all easy and to date no definite study has been conducted to pinpoint the cause of these recurring mishaps., nor has a meaningful solution been derived to address training shortfalls for junior surface warfare officers.

In Table 4 we examined the objects of each collision mishap. Basically we wanted to examine what objects -- other than another ship that U.S. Naval vessels were likely to collide with. Analysis of the data revealed that over a third of the mishaps involved other U.S. Naval vessels. Both fixed and floating objects or structures were a close second as being the most frequent objects of collisions.

Another area for consideration and analysis was that of the operational environment. We thought it would be prudent to try to determine when the likelihood that a collision would and did occur (i.e. transiting restricted waters, formation steaming, conducting underway replenishment, or etc.).

The data revealed several scenarios in which a U.S. Naval vessel would most likely be involved in a collision. We considered this to be very vital simply because it offers type

| Object of Collision | 80 - 82 | 83 - 85 | 86 - 88 | 89 - 91 | 92 - 94 |
|---|---|---|---|---|---|
| Naval Ship | 65 (47%) | 72 (43.6%) | 33 (37.5%) | 39 (35.4%) | 15 (37.5%) |
| Merchant Ship | 17 (12.4%) | 15 (9%) | 11 (12.5%) | 19 (17.2%) | 1 (2.5%) |
| Pleasure Craft | 2 | 2 | 2 | 1 | 3 |
| Fishing Craft | 0 | 2 | 4 | 2 | 1 |
| Military Ship Other Than Naval | 1 | 1 | 3 | 3 | 0 |
| Fixed Structure | 25 (18.2%) | 17 (10.3%) | 7 (7.9%) | 11 (10%) | 7 (17.5%) |
| Floating Structure/ Object | 12 (8.7%) | 31 (18.8%) | 5 (5.7%) | 9 (8.18%) | 3 (3%) |
| Submerged Object/ Structure | 6 | 7 | 4 | 3 | 0 |
| Unknown Ship, Craft, Object or Structure | 1 | 3 | 0 | 1 | 0 |
| Submarines | 7 | 6 | 2 | 2 | 1 |
| Tug | 1 | 7 | 13 | 15 | 9 |
| MISCELLANEOUS | 0 | 2 | 4 | 5 | 0 |
| TOTALS | 137 | 165 | 88 | 110 | 40 |

**Table 4: Objects of Collisions**

commanders and their staffs an opportunity to develop meaningful training objectives for remedying these training shortfalls. Table 5, surprisingly revealed that the majority of all reported collisions occurred when vessels were involved in basic mooring and anchoring evolutions. It is during this particular period, that the skills of a shiphandler are most apparent (i.e. getting underway from a pier, returning to port and mooring to a pier, etc.). To successfully perform each of these tasks, the shiphandler must be very competent in his/ her skills. They must exercise more than just a general working knowledge of basic shiphandling, but know to a more precise detail -- the total impact of basic shiphandling dynamics and thoroughly understand the direct impact that each force plays on the handling capabilities of his/her individual vessel. Failure to do so -- as is evident by the data, often will lead to unwanted mishaps which ultimately result in costly damage to equipment and possible personnel injury.

| EVOLUTIONS | 80-82 | 83-85 | 86-88 | 89-91 | 92-94 | TOTAL |
|---|---|---|---|---|---|---|
| ENROUTE | 2 | 2 | 2 | 2 | 0 | 8 |
| EXERCISE FLT/SHIP | 9 | 12 | 7 | 4 | 2 | 34 |
| FORMATION STEAMING | 1 | 2 | 3 | 3 | 0 | 9 |
| GETTING UNDER-WAY | 10 | 28 | 11 | 13 | 2 | 26 |
| INDEPENDENT STEAMING | 7 | 10 | 2 | 11 | 9 | 39 |
| MOORING/ANCHOR-ING | 53 | 61 | 32 | 34 | 5 | 185 |
| UNDERWAY REPLENISHMENT | 16 | 13 | 7 | 19 | 5 | 60 |
| TRAINING | 1 | 0 | 0 | 1 | 0 | 2 |
| TRANSITING RESTRICTED WATERS | 16 | 12 | 5 | 9 | 3 | 45 |
| OTHERS | 22 | 30 | 15 | 14 | 14 | 95 |

**Table 5: Operational Evolutions**

In most collision mishaps, follow-on investigations will seek to determine who should be held at fault or who played a major role in contributing to the mishap. As in all cases involving U.S. naval vessels, the Commanding Officer is ultimately held responsible for the safety and behavior of his/her vessel. In Table 6, the information presented bears this fact. More often than not, the person found to be most responsible for the vessel's involvement in the mishap was identified as being, the Supervisor (or Commanding Officer) of the vessel, the Operator, (considered to be either the Officer of the Deck and/or Conning Officer), the Watchstander or some other individual.

| WHO | 80-82 | 83-85 | 86-88 | 89-91 | 92-94 | TOTAL |
|---|---|---|---|---|---|---|
| SUPERVISOR | 91 | 113 | 33 | 37 | 1 | 275 |
| OPERATOR | 12 | 23 | 9 | 39 | 24 | 107 |
| WATCHSTANDER | 30 | 16 | 3 | 6 | 6 | 61 |
| OTHER | 10 | 10 | 4 | 0 | 0 | 24 |

**Table 6: Human Cause Factors - Who?**

Tables 7 and 8 further provide information pertaining to the reasons why the individuals involved failed to act or take necessary measures to avoid the collision. Table 8, further identifies the reasons why they failed to take the necessary/appropriate actions.

| FAILED TO: | 80-82 | 83-85 | 86-88 | 89-91 | 92-94 | TOTAL |
|---|---|---|---|---|---|---|
| Correctly Operate Controls/Monitor Displays | 27 | 69 | 39 | 68 | 19 | 222 |
| Recognize Hazardous Situations | 46 | 35 | 3 | 4 | 3 | 91 |
| Use Proper Caution for Known Risk | 21 | 11 | 3 | 6 | 3 | 44 |
| Plan Adequately | 7 | 15 | 0 | 1 | 4 | 27 |
| Supervise Progress of Work | 3 | 6 | 0 | 3 | 1 | 12 |
| Take Corrective Action<br>(TIME WAS AVAILABLE) | 26 | 11 | 0 | 0 | 1 | 38 |
| Coordinate Tasks | 2 | 4 | 0 | 0 | 0 | 6 |
| Others | 11 | 11 | 4 | 0 | 0 | 26 |

**Table 7: Personnel Cause Factors - Failed To**

As indicated by Table 7, the most frequent cause factor for the individual(s) involved in the reported mishaps was that they simply failed to correctly operate particular controls and/or monitor various navigational displays. The second most significant cause factor was identified as clearly being a failure on the part of the individual(s) to recognize the hazardous situation as it developed. As is clearly stated in COLREGS, there are definite indicators by which a mariner is able to determine whether or not he/she has entered into a situation which if not responded to in a timely and appropriate manner will result in a risk

| WHY FAILED | 80-82 | 83-85 | 86-88 | 89-91 | 92-94 | TOTAL |
|---|---|---|---|---|---|---|
| DISTRACTED/ INATTENTIVE | 42 | 92 | 39 | 82 | 8 | 263 |
| LACK OF CONCERN/ INTEREST | 4 | 9 | 0 | | 1 | 14 |
| INSUFFICIENT EXPERI-ENCE/SKILL/TRAINING | 23 | 14 | 1 | 14 | 1 | 53 |
| FAILURE TO DETECT WARNING SIGNAL/INDI-CATION | 20 | 10 | 4 | 1 | 2 | 37 |
| INADEQUATE KNOWL-EDGE OF PERSONNEL/ EQUIPMENT | 14 | 17 | 0 | 9 | 0 | 40 |
| DEMEANOR | 48 | 17 | 0 | 8 | 1 | 74 |
| OVERCONFIDENCE | 48 | 41 | 3 | 4 | 1 | 98 |
| MISUNDERSTANDING | 5 | 11 | 1 | 1 | 0 | 18 |
| DISRUPTED COMMS | 11 | 7 | 5 | 2 | 0 | 25 |
| OTHER | 38 | 7 | 8 | 4 | 3 | 60 |

**Table 8: Personnel Cause Factors - Why Failed?**

of collision. It is apparent by the case histories provided to us by the Naval Safety Center and those provided included in Appendix B, that the opportunity to prevent each of these unfortunate mishaps was present and if not for the failure of the parties involved, they could have been avoided.

As previously stated, each of these mishaps could have been avoided if the parties involved had taken appropriate and timely action when possible. However, Table 8 illustrates a number of the most frequent reasons as to why the individuals involved failed to take the necessary and prescribed by the Nautical Rules of the Road, as delineated in COLREGS. Without a doubt, the single most common contributor was that the involved party was either distracted or was inattentive to the surroundings or navigational environment, closely following that was the demeanor or overconfidence of the individual(s) involved.

Throughout this entire project, we have been amazed by the fact that those throughout the navy whose job it is to gather, monitor, and analyze this data have failed to identify this apparent trend in these mishaps. We are equally surprised that they have failed to at least make mention of the fact that there perhaps is a real problem in the way that we in the Navy, approach the training of our young junior officers in the development of safe, prudent, and competent shiphandling skills. The obvious result of this failure has been a tremendous expenditure in dollars to repair damaged equipment, to provide medical care to the countless numbers of personnel injured during these mishaps, and in some cases the enormous price paid in promising young careers and lives. What will such a system as the one we propose cost by comparison to the dollars expended to repair the damage already suffered? Table 9 summarizes the historical costs.

| Cost Range | 80 - 82 | 83 - 85 | 86 - 88 | 89 - 91 | 92 - 94 |
|---|---|---|---|---|---|
| > $1 M | 9<br>($24.8M) | 5<br>($13.8) | 4<br>($15.5M) | 3<br>($19.8M) | 3($19.8M) |
| >$200k - 1M | 9<br>($3.9M) | 18<br>($9.5M) | 7<br>($3.2M) | 10<br>($6.9M) | 4<br>($2.2M) |
| > $10k - 200k | 57<br>($3.7M | 64<br>($3.7M) | 28<br>($1.6M) | 23<br>($1.4M) | 11<br>($507K) |
| 0 - 10K | 39<br>($94K) | 47<br>($141.5K) | 29<br>($90.4K) | 47<br>($136K) | 13<br>($30K) |
| TOTALS | 114<br>($32.5M) | 134<br>($27.2M | 68<br>($20.4M) | 87<br>($38.2M) | 31<br>($22.5M) |

**Table 9: Cost of Collision Mishaps**

## C. A LOOK AT THE PAST - CASE HISTORIES

Appendix B provides a series of case histories which were extracted from the historical data being maintained by the Naval Safety Center. Choices for inclusion in this report were basically made on a random basis. These cases clearly illustrate situations where the junior's officer's decision making ability, as well as response to the impending mishap might have enhanced if he/she had received a more directed training program designed to improve his/her situational awareness? Would his/her ability to make a choice which would or could have prevented or lessened the impact of the mishap, thus resulting in minimal damage to his own vessel and/or that of the other vessel or object involved?

In each of the cases presented, a junior officer of the rank of Lieutenant (O-3, less than 10 years commissioned service typically). The question that is raised is whether or not these young officers given the experience to participate in a non-threatening environment such as the multi-ship training simulator proposed by our research could have played some beneficial role in developing that all important seaman's eye and additionally allowed for better reaction to situations as the Shiphandling Simulators as Training Tools

Electronic and computer/based simulators have long been used as training tools in aviation and weapons training. Sophisticated simulators with displays have been available for flight training for over thirty years. However, visual simulation for shiphandling training is a recent development. Only within the last decade have dynamic, visual shiphandling simulators become available for training. Shiphandling simulator development was encouraged by the need to study the movement and control of the very large oceangoing tankers which were making their debut in the mid 1970's. The technology continued to improve until nearly every kind of ship and hydrodynamic effect could be faithfully recreated in today's simulator.

### 1. U.S. Navy's Use of Shiphandling Simulators

In the 1980's, the United States Navy decided to make use of available shiphandling simulator technology in the training of its mid-grade and senior officers preparing to return to sea duty. With very little, if any, experience in shiphandling simulator training technology, the Navy sought and found the services of a private commercial firm to develop the necessary training facilities to study the effectiveness of such an advanced training tool.

The contract was awarded to Marine Safety International (MSI), a New York based firm to create a shiphandling simulator complex at the Surface Warfare Officers Training Facility located in Newport, RI. To date, MSI provides these services for the Navy at an estimated cost of 1.5 million dollars annually. Training is administered as part of the prospective department head, prospective executive officer, and prospective commanding officer course conducted by the Surface Warfare Officers School Command. The simulator is a complex, realistic, and vital part of the pipeline leading to duty as department head, executive officer, or commanding officer in the fleet today. The course curriculum consists of:

- 20 hours Advanced Shiphandling Training (commanding officer/executive officer level students).
- 20 hours Intermediate Shiphandling Training (normally department head level students).
- 40 hours Advanced Shiphandling Training for Aviation Officers (aviator, navigator, assistant navigator, executive officer, commanding officer students).

The facility has been designed specifically for visual training. When allied with a well thought out curriculum and used by an experienced instructor, these simulators will measurably increase the shiphandling ability and confidence of its users. Some of the more recent feedback provided by recent attendees further serves to support the positive impact and role these training simulators have played to date are as follows: [SWOS94]

- Without reservation the simulators were thought to be extremely beneficial in preparing them for return to sea duty.
- Overall learning curve of concepts was reduced significantly.
- Level of professional experience exemplified by each instructor made for a positive environment conducive to learning.
- The one-on-one advice offered by instructors during each phase of training, was both timely and insightful.

- Presented a great first introduction to the destination ship type.
- Course continues to be some of the most valuable training a shiphandler can receive.

However, as in all cases in life, there were several areas which students felt the simulator training program lacked or could stand to be improved:

- Course content did not aid in teaching the basics of shiphandling. Course just failed to provide experience in multiple at sea scenarios (i.e. underway replenishment, piloting in restricted waters, night steaming, formation steaming, multi-ship tactical maneuvering).
- Not enough time allowed for each student to comfortably participate in the various scenarios.
- The demographic make up (i.e. rank structure) caused some intimidation in some students.
- Failed to address shiphandling when in emergency conditions (i.e. high seas, various engineering casualties, man overboard, etc.)
- Insufficient time to cover all of the available course material.
- Too much time taken to facilitate playback of previous exercise scenario(s).
- The course curriculum failed to consider the experience level of its reporting attendees and thus, was inflexible in meeting their needs. The format was considered to be either too fast or too slow in areas [SWOS94].
- Not accessible enough.
- Needed to expand the different ship types. No information or models covering the large amphibious class ship types.
- Little or no training regarding the use and operational procedures of tugs.
- Course tended to focus on poor piloting practices.
- Not enough of emphasis spent on teaching standard shiphandling commands.

## D. OBJECTIVES AND SCOPE

This research project encompasses a number of objectives, however, several principle objectives have become central to the main focus of research efforts as the project evolves into the implementation phase. Specifically research efforts were focused in the areas of:

- Development and implementation of a deployable three-dimensional virtual world shiphandling training simulator,
- Design and development of terrain database for virtual world simulation (to include cultural structures, shoreline, aids to navigation (both fixed and afloat), ships at anchor, and moving vessels),
- Modeling ships and other maritime vessels,
- Modeling of real-time hydrodynamic forces acting upon those maritime entities within the virtual world environment, and
- Implementation of the simulator into a networked environment using NPSNET IV.

The intended scope of this project will include, but not be limited to, the following additional objectives:

1. The development of a training system that provides greater training availability for more junior officer personnel who normally do not receive exposure to land-based full scale training simulators until later on in their naval careers.

2. Addition of afloat assets into NPSNET battlefield simulation to allow for joint forces interaction in a virtual at-sea environment.

3. The capacity for further expansion which includes additional shiphandling training scenarios and ship functionality.

4. Development of object-oriented programming techniques which would enhance the functionality of response model prototypes and reduce overall development timetables.

5. Development of physically-based modeling techniques involving the hydrodynamic forces acting on a ship, given limited processing capability.

6. Design and development of a three-Dimensional seaport which represents a selected geographic area and associated maritime shipping from converted Defense Mapping Agency (DMA) data.

## E. RESEARCH QUESTIONS

1. Can a deployable version of a real-time, dynamic shiphandling simulator be developed which provides training with a high degree of realism as current full scale, shore-based mock-ups?

2. What degree of hydrodynamic effects can be accomplished with the processing capability of a deployable version of a shiphandling simulation trainer which will be required to provide a high degree of realism of moving a ship through water?

3. How can objects/entities such as bridge equipment normally available on full scale bridge mock-ups/training simulators be modeled and incorporated into a deployable simulator and provide real-time or near real-time functionality?

4. How can a restricted waterway and open ocean database be developed to provide realistic topographical and hydrographic features (e.g. depth, currents, hazards to navigation...etc.)?

5. Can the proposed system be incorporated into a networked environment (e.g. NPSNET IV) to support open-ocean maneuvering scenarios and near-land amphibious battle problems, tactical planning, and training which may involve amphibious assault training and planning?

6. Can a real-time virtual system be developed which provides for real-time playback capability to allow for visual feedback during the post training phase of the training?

7. Can basic environmental effects (i.e. fog, rain, etc.) be implemented into the training simulator so as to provide a true depiction of real world factors experienced when at sea?

## F. SUMMARY OF CHAPTERS

Chapter II provides a review of previous research conducted in the area of visual simulation system design. There have been a number of major contributions made in this area, however, a limited amount of research has been conducted in designing and developing virtual simulation systems, with the end purpose of serving as shiphandling training vehicles. Chapter III provides an extensive description of both the full-scale simulator facilities currently being contracted by the United States Navy, for the purpose of providing training services to its senior and mid-grade officers. It further provides a comparison between the full-scale systems and the portable/deployable version resulting from this research. One of the significant design objectives of our shiphandling simulator was the creation of a high fidelity terrain database, possessing rich scene content, so as to enhance the degree of realism experienced by conning officers making use of the system. In Chapter IV, we offer some insight into the design of the system by discussing many of the design issues considered in the reproduction of the various viewpoints experienced when underway on the bridge of a ship in a familiar sea port. Chapter V examines the hydrodynamic force modeling concepts employed. Here, we examine those hydrodynamic coefficients unique to the models of U.S. Navy surface vessels used in this research. Chapter V discusses the systems current graphical user interface design and further discusses the limitations experienced when using the Performer’s limited selection of interface functions in its development. In Chapter VI, we introduce one of the most dynamic three dimensional modeling applications available in the newly evolving field of virtual environment technology (VET) -- MultiGen, and discuss some of its basic functionality and techniques for development of three dimensional models for use in our shiphandling environment. Given the extensive experience gained in the development of this project, in Chapter VIII, we expound on some of the methods employed to develop the terrain database created for our shiphandling system. Additionally, we offer several suggestions for improving the terrain database development process and recommend several possible resources for obtaining Defense mapping Agency Data and materials which aided in the design and development process. Chapter IX discusses the techniques, procedures, and results of the system usability study conducted. It briefly discusses the characteristics of the Heuristic and Cognitive Walkthrough techniques which are widely used in the study and evaluation of today's highly complex software systems. We will conclude with Chapter X, by presenting final conclusions derived from the research and offer several suggestions for future research which we strongly feel will further enhance the overall effectiveness of the system. Several Appendices are included, one consisting of a complete users's guide, which provides step-by-step procedures for operation of the simulator.

# II. REVIEW OF PREVIOUS RESEARCH

This chapter, briefly examines the research efforts made in the area of VW design, development, and implementation, which played a significant role throughout the evolution of this research. Further, we attempted to review in some detail those efforts and contributing research data which have made possible the complete design, development, and final implementation of the first real-time, three dimensional, distributed interactive simulation (DIS) compatible, open-ocean training simulator developed here at the Naval Postgraduate School.

## A. PREVIOUS RESEARCH AT NPS

### 1. Young

In September 1993, R. David Young completed research in the area of Distributed Interactive Simulation (DIS) protocol compatibility. The goal of his research was to develop a new NPSNET simulator to allow simulations with any simulator that complied with the DIS protocol [YOUN93]. He further attempted to provide a more realistic, real-time simulation by maximizing the use of the Silicon Graphics Inc., (SGI) Reality Engine; and to provide for future extensions to the system.

The approach taken was to simply employ one of the premier real-time, 3-D toolkits currently on the market -- SGI's IRIS Performer. Performer is unique in that it is able to directly access the Reality Engine hardware, thus making full use of its multiprocessing management capabilities, and its real-time scene-rich management, thus allowing for integration of more realistic models and higher rates of movement in virtual environments. Additionally, Young was able to use existing modeling tools (e.g. MultiGen, a product of MultiGen Inc.), in the development of his simulation database.

With MultiGen, he was able to reduce his overall production time (i.e. modeling man-hours) in producing 3-D models for his virtual environment. Although modeling techniques was not one of the goals of his research, he invariably was able to learn new techniques which proved to be important aspects in the design of a virtual database for real-time scene management. Through these techniques, he was able to derive methods which allowed him to sustain an established industry standard for VW systems, that being a minimum of ten frames per second to support the concept of immersion [BRYS93]. Several of his development practices have aided in the successful completion of this research effort. Later in Chapter VII -- Terrain Database Development, we will further expound upon these modeling development practices and several others which have greatly impacted our work in this area.

Later to attain his objective of enhanced systems extensibility, Young employed a number of C++ object oriented classes, which greatly improved the encapsulation of system entity behaviors and user inputs [YOUN93]. This important research in like manner resulted in one of the fastest growing, (i.e. amongst DOD components) highly flexible, and dynamic public domain simulation systems available today -- known as NPSNET-IV.

NPSNET-IV makes use of the DIS protocol to interact with other heterogeneously developed simulators as was demonstrated in a week long simulation between NPSNET-IV and two different simulation systems written by the Air Force Institute of Technology [YOUN93]. NPSNET's capabilities were demonstrated to be numerous, in that it allowed for users to interact with three-dimensional terrain, structures, and other players within the world. More will be said about NPSNET in later chapters of this report.

### 2. Covington

As in the case with all software systems, NPSNET-IV was being developed at an enormous rate to allow full beta testing and implementation. Although the design was sound, the actual development and configuration management of the software was somewhat less efficient than what it could have been. Thus, James Covington's research efforts were focused toward reviewing the code's current data structures and functions and to subsequently enhance the systems overall performance by making them more efficient.

His efforts resulted in the creation of an open ocean environment, which provided a conceptual representation of the ocean surface that realistically animated waves in real-time and further coordinated the dynamic motions of simulated marine vehicles sailing on the surface [COV93]. Additionally, Covington developed a Motif-based, object-oriented graphical user interface that could be used in a Performer multiprocessing application.

As in the case with Young, Covington's work also resulted in the development of a set of C++ classes that contained both the necessary data and methods to describe the ocean surface as a spatially organized hierarchy of dynamic geometric structures. An additional end-product of his work resulted in the Ocean and Wave classes currently found in the NPSNET-IV system. This resulted in an extension of the NPSNET vehicle class, thus accomplishing the all important goal of -- enhancing the extensibility of the NPSNET system.

**3. Zeswitz**

In developing the earliest version of NPSNET, system designers made use of non-standard network protocols which greatly exempted its participation in a distributed simulation environment. As DIS [IST93] began emerging as the international standard for distributed simulation, it provided more definitive protocol standards to developers seeking to create simulation systems.

To ensure the NPSNET system kept pace with state of the art simulation systems development, Stephen Zeswitz's research sought to develop a robust, high-performance implementation of the DIS Version 2.0.3 protocol to support graphic simulation systems [ZESW93]. The end result was the foundation of a DIS Network Library, consisting of an application program interface (API) to low level network utilities, and a network harness that took full advantage of multiprocessor workstations [ZEWS93].

This research made extensive use of the distributed networking capability by allowing users to enter at their respective SGI workstations and selecting their desired ship-type/class, and furthermore allow for direct interaction with other users of the simulator in a three dimensional real-time virtual environment. Such capability was made possible due to the fact that NPSNET-IV makes use of a BSD 4.3 socket based interprocess communication (IPC) to provide a clear, easily used, and well documented network interface [ZESW93]. This feature further allows for development of a much more dynamic and functionally scene-rich training platform for training junior surface warfare officers in prerequisite shiphandling skills and most importantly the “seaman’s eye.” In Chapter III, further details on the software architecture and basic user interface will be discussed.

## B. RESEARCH EXTERNAL TO NPS

There were a number of papers published on research in the area of virtual building environment development, however, very few have been written pertaining to the actual design and development of terrain database systems. In order to accomplish the successful design and development of such databases; several of the papers were reviewed and only those which possessed concepts unique to our design and development process will be discussed.

What makes this research effort so unique, is the fact that we are working with a large-area geographical location (i.e. San Francisco, CA). In doing so, we attempted and successfully developed an application with the application of training junior surface warfare officers in the development of both proper shiphandling and situational awareness skills.

### 1. J.M. Airey, J.H. Rohlf, and F.P. Brooks

Although the sum total of their research was centered on the development of virtual building environments, there were some very relevant facts which we found to be significant to our research. Basically, Airey, Rohlf, and Brooks, examined the performance impact of virtual world (VW) development and how best to optimize overall system development in order to achieve the best possible performance.

As depicted in Eq. 2.1, their research deduced that there were two strategies which can be employed to aid in combining interactivity with high image quality in a virtual building simulation (i.e. pre-computation before display and adaptive refinement during display) [AIRE90]. Although our goals were toward the same end, we found the below listed concepts to be directly related to development of our virtual environment. They felt that a complete system must have the following major parts:

- A modeling subsystem whereby the canonical model is maintained.
- Employment an image generation process for constructing a display file from the canonical model and then generating the images.
- An interface subsystem that allows the use of many different man-machine interface devices for controlling viewing parameters and lighting circuit settings.

An additional stated criteria as stated by Airey, Rohlf, and Brooks, stated criteria was to find one a modeling subsystem, that met the goal of addressing “ease of construction (i.e. how many man-hours are required to create the model), model modification, and management of many different versions of the model (a task very similar to source code control) [AIRE90]. For our project, we chose MultiGen as our principle modeling subsystem. (See Chapter VI for further information regarding MultiGen and its capabilities)

Finally, just as significant was the selection of an interface subsystem which coordinates input devices with the display system. In our current design, the device of choice was simply a mouse. Although simple in operation and design, we felt this device offered a very flexible interface for the user. Moreover, comparative experiments on the mouse vs. other pointing devices have shown the mouse to be faster [CARD78]. With little analytic theory we can derive more insight. From the Model Human Processor we can derive that fact that the time to position the hand on the target is given by Figure 1 below.

$$PositioningTime = C + K \cdot \log(D/S + 0.5) \qquad \text{(Eq 2.1)}$$

In Eq 2.1, D is the distance to the target, S is the size of the target, and C and K are constants. In fact, it fits with about the same constant of proportionality K of 0.1 sec/bit that the hand does [CARD78]. This tells us that the key constraint on pointing time is not in the mechanism of the mouse, but the eye-hand coordination system of the user. One additional contributing factor which allows the system to maintain this flexibility, is the use the graphical user interface (i.e. the widgets provided in the Performer library).

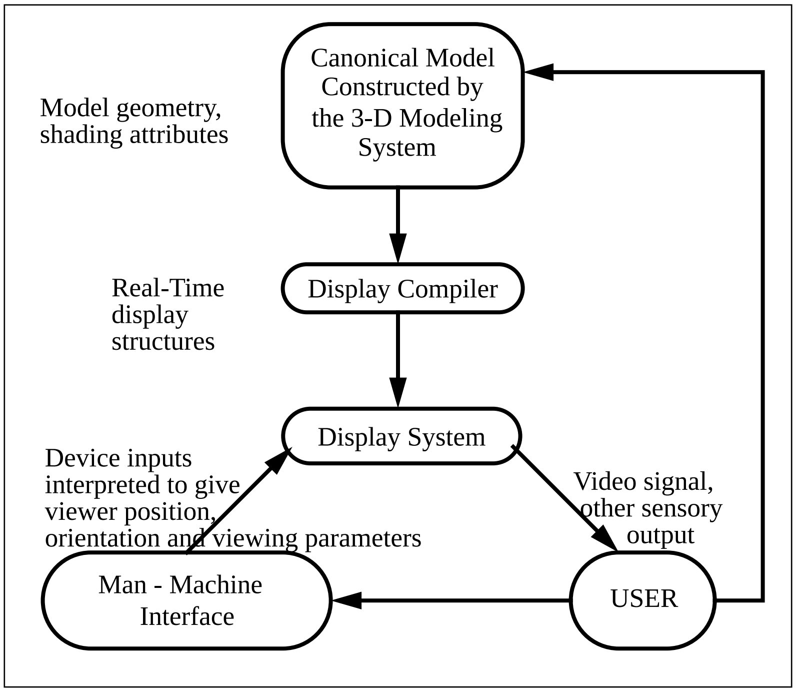


**Figure 1: Overview of Virtual Development System**

**2. G. Grinstein, P. Breen, and A. Cheng**

It is common knowledge among VW developers, that most of the time to develop virtual simulation applications is spent in the modeling of its objects. Additionally, the process of modeling (i.e. creating graphical objects) demands the majority of the human effort invested in most computer-graphics applications [KOCH91]. In this paper researchers describe a solution to the problem of modeling development in certain applications in which object fidelity and level of modeling detail is not the primary requirement [GRIN94]. Although Young touched upon several techniques for enhancing three-dimensional model development, the focus of his research was not centered on deriving such techniques.

In the research conducted by Grinstein, Breen, and Cheng [GRIN94], we find several concepts which were developed to enhance workstation images, three dimensional stereoscopic large screen display products, and realistic three dimensional sound outputs as well as voice input, hand gestures, and postural inputs to synthetic models. Consequently effective and efficient virtual world development evolves around the developers ability to make use of those modeling applications and editing tools readily available (i.e. MultiGen, AutoCAD, Adobe Photoshop, etc.) to him/her. Through successful management of these tools and their application, an entirely new concept called virtual environment technology(VET) has now been created which supports the creation of natural, often intuitive, user interfaces for synthetic models [GRIN94].

Hence the developer must make specific decisions regarding the end product sought. In other words, the design, development and implementation of any VW system must deliberately consider simple, but important concepts that will lead to an acceptable final simulation product. We discuss later in the report, those design and development concepts which have led to the successful completion of this simulation system.

**3. Michael Jones**

According to Jones, interactive computer graphic simulation of virtual environments has become widespread since the 1960's. The use of real-time image generation for military aircraft training, armor training, commercial pilot training, and astronaut training has become so common that there are very few of these skilled people who have not been exposed to simulation training in one form or another. With the increasingly downward trend in simulation costs, the number of applications using these techniques has increased tremendously in recent years [JONE94]. Consequently, there are many precepts regarding the design of visual simulation systems, however, there has been no definitive record as to what the actual design process should look like.

In a recently published paper by Michael Jones of Silicon Graphics, Jones provided many key insights developed by real-time graphics pioneers as they developed the first simulation applications and suggests how these innovations can be incorporated in the design and implementation of current and future entertainment projects [JONE94]. These techniques are listed below in Figure 2.

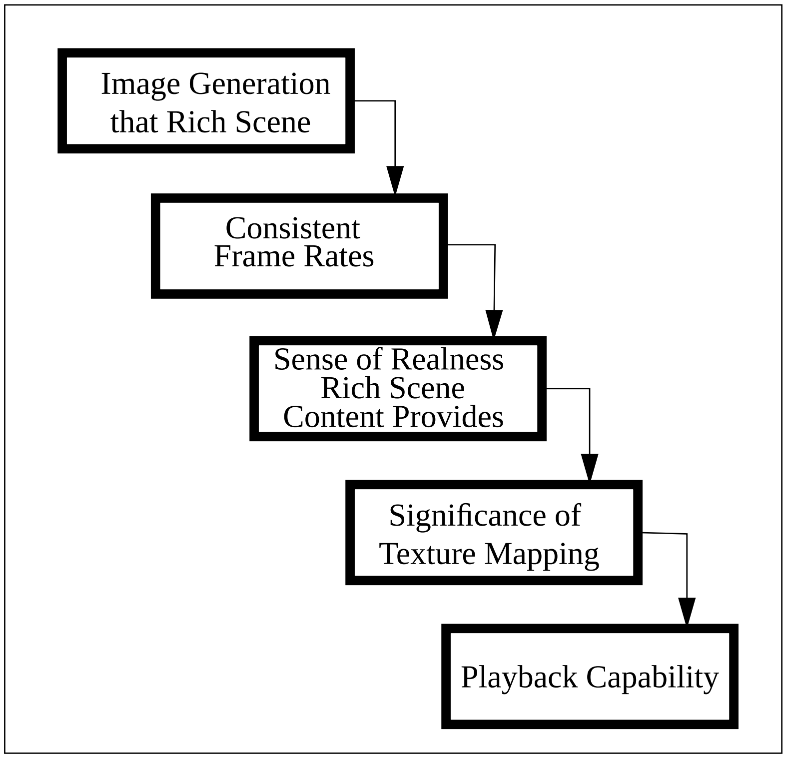


**Figure 2: Precepts of Visual Simulation Design**

Accordingly, many of these techniques were employed in the design and development of this project and will receive extensive discussion later in the report.

# III. SHIPBOARD SIMULATOR DESCRIPTION

## A. DESIGN PHILOSOPHY

### 1. Existing Bridge Simulators

There are two full scale shipboard bridge simulation training facilities in existence dedicated, but not restricted to training U.S. Navy bridge watchstanders. These facilities, located in Newport, RI and San Diego, CA, are operated by Marine Safety International (MSI), a private contractor, and staffed with technical personnel to operate the equipment and professional instructors (usually licensed ship masters) to provide instruction to the student watchstander. The objective of these facilities is improve a conning officer's "seaman's eye" [MSI93] by providing an environment where a conning officer under training actually perceives that he or she is on the bridge of a ship underway. To give the impression of a ship's bridge, the full-scale simulators are constructed with the visual features of a ship's bridge as a flight simulator is fashioned with the visual features of the cockpit of an aircraft. With the aid of numerous computer processors, the complex maneuvering and hydrodynamic characteristics of the full-scale simulator or virtual ship are dynamically calculated in real time and applied to the simulation given the various maneuvering inputs applied by the student. The overall accuracy of the full-scale simulator's ship's movement is guaranteed to be within an accuracy of seventy percent of the particular ship that is being represented [NRCC93].

The full-scale simulator's bridge (Figure 3) has been constructed to resemble a real ship's bridge and equipped with the safety and navigation equipment normally found on a real ship's bridge such as radar repeaters, navigation equipment, communications equipment, course and speed indicators and engine status displays. Windows are provided to look out at the virtual waterway, which is projected on large screen displays located behind the windows. In addition to the display of the waterway, the foredeck of a the

**Figure 3: Full-Scale Simulator's Bridge [MSI93A]**

particular ship being represented is also displayed to "remind" the conning officer of the ship that he/she is assigned to. The view of the foredeck is essential to a shiphandling simulation in that it obstructs the conning officer's view of objects that are close aboard the vessel as the foredeck on a real ship would, requiring the conning officer to change his/her view to ensure the safe maneuvering of the vessel. To maneuver the full-scale simulated ship, the conning officer utters standard voice rudder and engine commands to another person also located on the bridge at a control console or helm. A minor restriction observed in the full-scale simulator's bridge is the lack of port and starboard bridge wings which are located on each side of and external to the bridge of a real ship to allow flexibility in viewing objects that are close aboard or abeam of the ship. Such bridge wings are only provided for in separate simulators which are detached from the bridge (Figure 4) and are dedicated solely to exercises that are specifically performed from the bridge wings such as mooring to a pier or conning alongside for underway replenishment. With the lack of bridge wings, the conning officer's view of the scenario is restricted to the direction that the ship is moving and is unable to check for objects off the beam of the ship prior to making a turn as the conning officer is taught in the early stages of training.

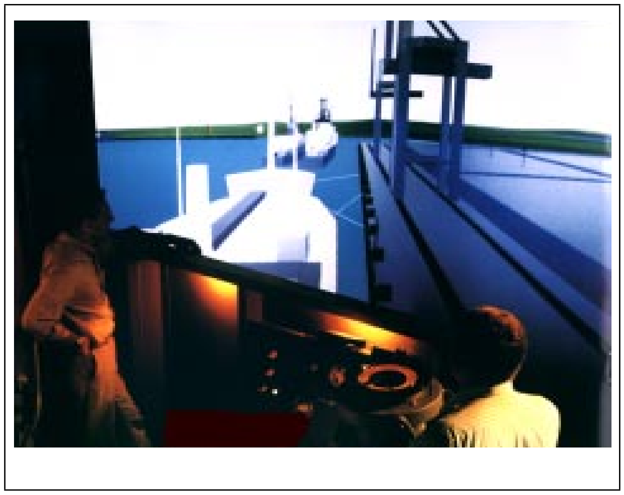

**Figure 4: Bridge Wing Simulator [MSI93A]**

This issue has been addressed by numerous students who have received training from the full-scale simulator facilities [MSI94]. It is our belief that it is imperative that the conning officers have a means of looking abeam and aft of the ship.

### 2. Portable Shiphandling Simulator

The design objectives of the portable shiphandling simulator were to provide similar types of realistic shiphandling training scenarios provided by the full-scale simulators described above utilizing a single, high-speed graphics workstation as a host, preferably a Silicon Graphics Inc. Reality Engine series model. The purpose of hosting the portable simulator on a single workstation was to allow its placement either aboard a deploying vessel or in the immediate vicinity of one that was in port (possibly on the pIer adjacent the ship).  This close proximity provides easy access to any shipboard personnel desiring shiphandling practice without the need for numerous support and technical personnel normally associated with the full-scale simulator to run the training scenario(s).

The training scenario is displayed in a split screen configuration (Figure 5) on a single, high resolution monitor with the display of the ship and its surrounding scene occupying the upper three quarters of the display and the ship's controls (provided by a simple graphical user interface) occupying the lower quarter. This method of displaying the scene and controlling the virtual ship enables the simulation scenario to be performed on a single workstation operated by a single user thus eliminating the need for special external interface devices found on the full-scale simulator (i.e steering wheels). For more enhanced training, the portable shiphandling simulator also has the capability to operate in a distributed network configuration, thus providing multiple ship, multiple user interaction and scenarios where different portable shipboard simulators on the network would act as different ship entities.

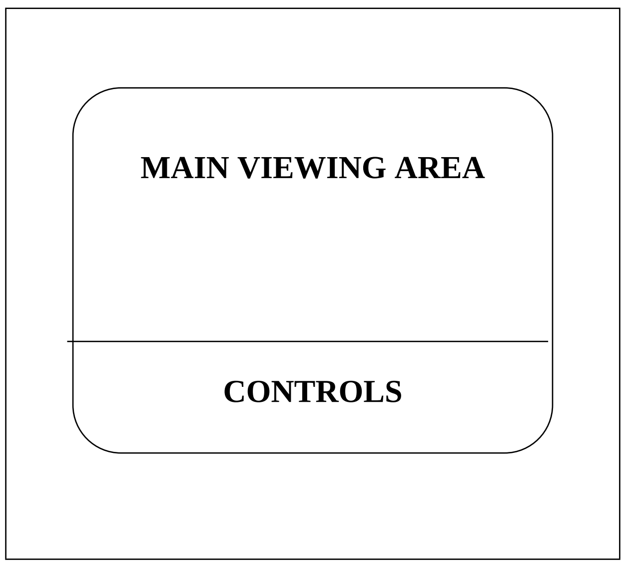


**Figure 5: Split Screen Display**

## B. THE PORTABLE SIMULATOR BRIDGE

When designing the portable simulator, the task of modeling the movement of the ship was not the only problem. The ability to place the conning officer onto a virtual bridge and allow freedom of movement among specific conning stations or viewing locations also needed to be considered. In addition to moving about the bridge, a form of head movement needed to be implemented where the conning officer could rotate his/her view to the desired viewing angle off the bow or raise and lower the view with respect to the horizon. The approach to solving these problems was to attach the conning officer's viewing position to one of three possible locations on the ship model: the pilot house, the port bridge wing or the starboard bridge wing. Movement between these positions is accomplished through inputs from the control panel. In essence, the conning officer is immersed into the scene by "riding" the model as it moves through the terrain database. When viewing forward, in line with the bow or off the beam, the conning officer will sense forward motion as the ship moves forward.

Upon program execution, the viewing location of the scene defaults to a location just forward of the ship's pilot house (Figure 6). The conning officer will see the foredeck of the ship as he/she would on a real ship along with the water and any landmarks that are directly in front of the ship. By manipulating controls on the control panel, the conning officer can change his/her view with respect to the ships bow 160 degrees left or right off the bow. Up and down head movement with respect to the horizon is also adjustable from

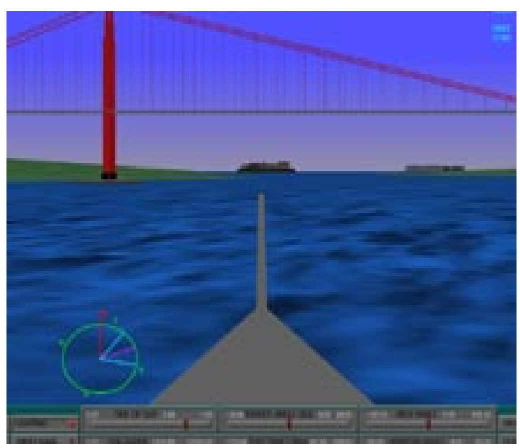

**Figure 6: View from the Virtual Bridge**

the control panel. By combining changes in viewing positions with head movement, the restriction that the full-scale simulators impose with viewing objects that are close aboard is overcome (e.g. looking down in the water from one of the bridge wings, viewing off the beam).

## C. CONTROLLING THE MOVEMENT OF THE SHIP

To allow the use of a single user, a simple means of controlling the ship's movement needed to be implemented. Conning officers control the movement of their ships by uttering standard rudder and engine voice commands to personnel managing steering and engine controls (as is done in the full-scale simulators). On the portable simulator, single user capability to control the ship's movement while viewing the scene was achieved by placing controls in the control panel immediately below the scene where they could be easily manipulated without distracting the conning officer's view of the scene.

## D. VIEWPOINT WHILE DETACHED FROM THE SHIP

In addition to the capability to change view location on the ship, the conning officer also has the capability to detach himself or herself from the ship and fly around the scene by pressing the FLY push-button on the control panel and manipulating the left and right mouse buttons to move in six degrees of freedom. With this function conning officers can position themselves in front of, behind or above the ship to better evaluate the effects of their control inputs during complex maneuvering evolutions such as mooring to a pier and the effects of these inputs on the overall posture of the ship. Furthermore, the conning officer can also fly ahead of the ship he or she is driving to observe maneuvering evolutions of other ship entities being reported over the network or scout ahead to better anticipate future maneuvers.

## E. BRIDGE EQUIPMENT AND INDICATORS

### 1. Azimuth Circle

One of the most essential components necessary in the safe maneuvering of a ship is an azimuth circle (Figure 7) mounted on top of a gyrocompass repeater. This device assists conning officers in determining new headings to steer and to obtain bearings of land marks to determine the position of the ship or bearings to other ships to judge whether a collision with another ship is imminent [MALO85]. Azimuth circles are located both on the

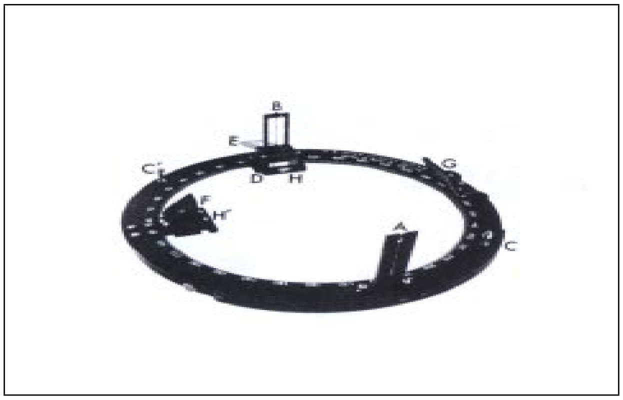

**Figure 7: Standard Azimuth Circle**

bridge and on the bridge wings to give the conning officer flexibility in obtaining bearings wherever he or she may be observing the movement of the ship. In modeling such a significant device for the portable shiphandling simulator, the azimuth circle needed to be accessed from the different viewing locations (bridge and bridgewings). To provide the functionality, a set of cross-hairs is displayed in the center of the screen to mimic an azimuth circle whenever the operator selects the AZ CIRCLE toggle button from the control panel (Figure 8). To obtain a bearing from an object, the conning officer changes

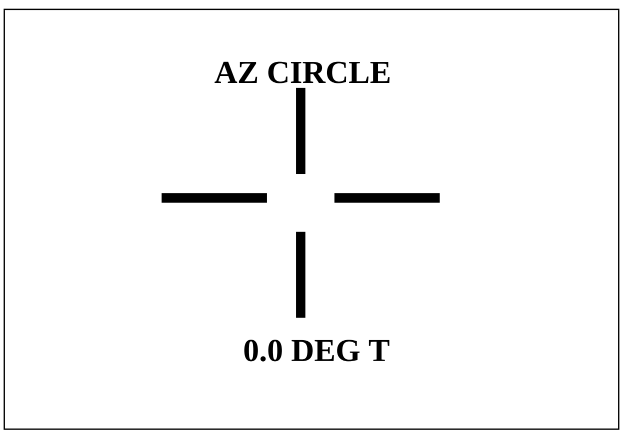


**Figure 8: Azimuth Circle for Portable Simulator**

the view angle using the VIEW ANGLE slide control. The cross-hairs remain at the center of the screen however, the bearing displayed below the cross-hairs changes as the view angle changes. To obtain a bearing from the ship to an object, the conning officer merely places the object between the cross-hairs and reads the true bearing below the cross-hairs.

### 2. Engine rpm, speed, position and rudder angle indicators

On just about every ship's bridge, indications for ship's speed, rudder angle and engine rpm's are normally displayed on analog devices such as gauges and scales located in various positions on the bridge where the information they provide could be easily obtained without removing the conning officer from his or her viewing positions. Limited by design to a single display device, the Portable Shiphandling Simulator continuously displays the information in the upper right portion of the main viewing area where the information can be easily and readily obtained from any viewing location or any viewing angle without distracting the conning officer from his or her desired view of the surrounding scene. The information is also available during the detached flying (FLY) mode.

## F. ENVIRONMENTAL EFFECTS

### 1. Time of day

To allow shiphandling practice during daylight and evening, a function was implemented to give the conning officer the ability to dynamically adjust the time of day of the exercise. When transitioning from daylight to evening, various objects in the scene become lighted and extinguish their lights when transitioning from evening to daylight. The intensity of daylight is selected from a slide control located on the control panel. The range of the intensity varies from zero to one with one being the highest intensity. This function only affects the scene of the ship being driven leaving other workstations in the network free to adjust their own time of days.

### 2. Fog

A fog generating function was included to give the conning officer practice in navigating in scenarios of low visibility. Fog may be turned on of off using a toggle button on the control panel. The range of the fog can be adjusted by the conning officer from one meter in front of the ship's bridge (totally obscured) to ten thousand meters. The default setting is two thousand meters. As with the time-of-day function, the fog function only affects the workstation of the driven ship.

## G. MISSION PLAYBACK

As an exercise is performed in real-time, the positions, speeds and times of positions of all the ships in an exercise are recorded for later playback. The playback mode provides a means of reconstructing an exercise to provide feedback to the conning officer as to what went wrong or what went right. Upon selection of playback mode from the control panel, the real-time exercise is terminated, the entities are returned to their initial positions and the playback of the exercise in begun. In addition to positions and speeds, the state of the driven ship which consists of the rudder angle and engine rpm's is displayed for a particular point in time to show the conning officer the particular ordered settings for these controls during the real-time scenario. Furthermore, an exercise playback clock is maintained to keep track of the time of each evolution. All of the functions except for engine rpm's and rudder angle are available while in playback mode. If the conning officer desires to change viewing locations or fly around the scene, those associated functions can still be used. Environmental functions are also available. To advance the playback to a later time or to pause it altogether, a fast forward slide control is provided on the control panel. The slide control ranges in value from zero to four with zero being a pause and four being the fastest speed of advancing the playback. A value of one is the default and represents normal playback speed.

## H. SAVE SCREEN FUNCTION

Depressing the SAVE SCREEN push-button on the control panel saves a still image of the entire screen. The image is stored in an RGB formatted image file.

# IV. SHIPHANDLING SIMULATOR ARCHITECTURE

## A. HIGH-SPEED RENDERING REQUIREMENT

One of the significant design objectives of the shiphandling simulator was the creation of high fidelity surroundings in the terrain database so that conning officers would feel as though they were underway on the bridge of a ship in a familiar sea port. Furthermore, piloting a ship in a restricted waterway requires accurate visual renditions of objects used as references to determine the position of the ship. To accomplish these goals we created a high detailed terrain database. Objects, such as landmarks (e.g bridges, wharfs,buildings...etc.) placed in this database required high numbers of polygons and textures to meet the visual high fidelity requirement.

Graphics rendering speeds or frame rates can be severely impacted by high polygon counts and textures. Real time simulations require a minimum of six frames per second for an interactive system with smooth motion beginning around fifteen frames per second [PRAT93]. A simulation of a ship moving through the water requires an adequate frame rate that shows continuous smooth motion of the ship and adequate response to maneuvering input. To attain these frame rates with such a large and detailed database, a Reality Engine series workstation was chosen as a host platform for the portable shiphandling simulator. IRIS Performer application programming interface (API) libraries were used to optimize the performance of the Reality Engine host. Another reason for using Performer was to facilitate the incorporation of the ship into the NPSNET battlefield simulation program.

## B. IRIS PERFORMER

### 1. Description

IRIS Performer is a software toolkit for creating real-time, three-dimensional visual simulation applications. Applications built using Performer's library can take advantage of

Performer's ability to optimize their performance on Silicon Graphics workstations[SGIA94].

## 2. Features

### *a. Multiprocessing*

Performer's most noteworthy feature is its multiprocessing capability which divides an application into separate simulation (or application), culled traversal and draw processes. The simulation process which can take place in more than one process, updates and queries the scene while the culled traversal process adds all potentially visible objects to a display list which is rendered in the draw process. Variables that may be needed in more than one process are stored within a shared memory arena.

### *b. Hierarchical run-time database*

Another prominent feature of Performer is its run-time visual database hierarchy (also referred to as scene). The visual database is a directed, acyclic graph (DAG) or tree of various types of nodes rooted at a node called a scene node (pfScene) (Figure 9).

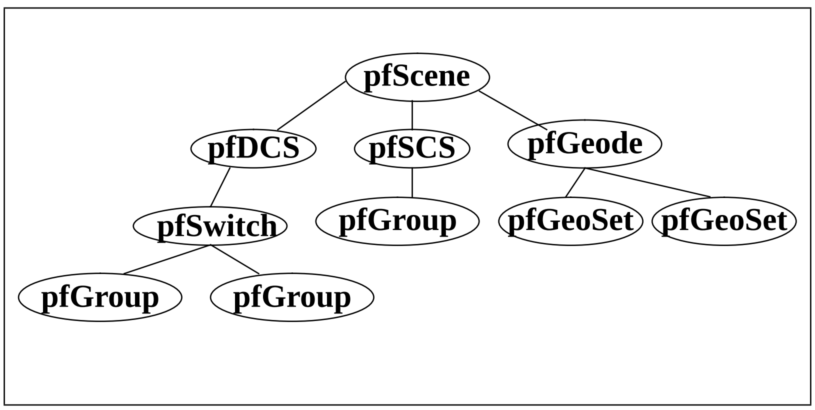


**Figure 9: Example of Performer Database Hierarchy**

A scene is rendered into a channel (pfChannel) or several channels which are culled and drawn in the graphics pipeline (pfPipe). The remainder of the nodes in the database include moving and non moving coordinate systems (pfDCS and pfSCS), nodes containing geometry (pfGroup, pfGeode), animations (pfSequence) and nodes to switch between different sets of geometry (pfSwitch). The actual geometry of the scene, including lightpoints is located at the leaf nodes.

### 3. Program flow

#### *a. Initialization*

The flow of every Performer program begins with a set of Performer and application specific initialization functions. Performer initializations include the allocation of shared memory (pfInit), setting multiprocessing mode (pfMultiprocess), configuring multiprocess mode (pfConfig), and setting of graphics pipelines (including the opening of a GL window) and rendering channels. Application initializations include the creation and initialization of shared memory data structures and creation of the scene hierarchy.

#### *b. Creation of the Scene Hierarchy*

The scene hierarchy is created starting with the scene or root node with child nodes added to the scene according to a logical or a spacial hierarchy. A logical hierarchy consists of a set of objects grouped under a common parent according to the object type regardless of position in the database whereas with a spacial hierarchy, the parent nodes that objects are grouped under correspond to a particular position in the scene. Geometry for the visual database may be created utilizing Performer's high speed rendering library (libpr) or created separate with a three-dimensional modeling application (e.g. Multigen, Wavefront...etc.). Geometry created separate from the Performer application is entered into the scene hierarchy using a load utility. When the initialization processes are complete, the real-time simulation begins.

#### *c. Real-Time Simulation Loop*

The real-time simulation of a Performer application consists of a loop that continuously calls the simulation (application), cull and draw processes. During the culling, the cull process traverses the nodes in the database and determines whether a node is within a channel's viewing frustrum. If a node is within the viewing frustrum, it is added to a display list which is later rendered by the draw process. The node's children are also checked for visibility and added to the display list based on the same criteria. A node and its children are ignored or pruned from the scene if they fall outside the viewing frustrum. If collision detection against objects in the scene is desired, the database is once again traversed testing the geometry attached to each node in the hierarchy for an intersection with a predetermined object (usually a line segment or pfSeg).

## C. PORTABLE SIMULATOR OBJECT HIERARCHY

The objective in mind when organizing the visual database hierarchy for the portable simulator (Figure 10) was to avoid unnecessary collision testing against objects located on land which ships normally do not run into. The root node or scene of the database has two child nodes -- a stationary (pfGroup) node to support non-moving objects such as the geographical terrain database (San Francisco Bay and surrounding area) and a moving (pfGroup) node which supports the ships which move through the database. The stationary node contains three (pfGroup) child nodes -- a terrain node which contains the geometry associated with the geography, a land objects node which contains the geometry of those objects located over land (buildings) and an offshore objects node which supports those stationary objects in the water that the ship can collide with (e.g. bridge, buoys, wharfs, etc.). All of the ships in the exercise are children of the moving node. The child nodes below the land, offshore and moving objects are a set of switch (pfSwitch) nodes to enable the switching between unlighted geometry that’s viewed during daylight and lighted geometry viewed in darkness. As the geometry is loaded and added to the hierarchy, it is assigned a collision mask which is used during intersection testing. Collision masks, in this case, are assigned such that geometry assigned to the land objects node is totally ignored for faster intersection testing.

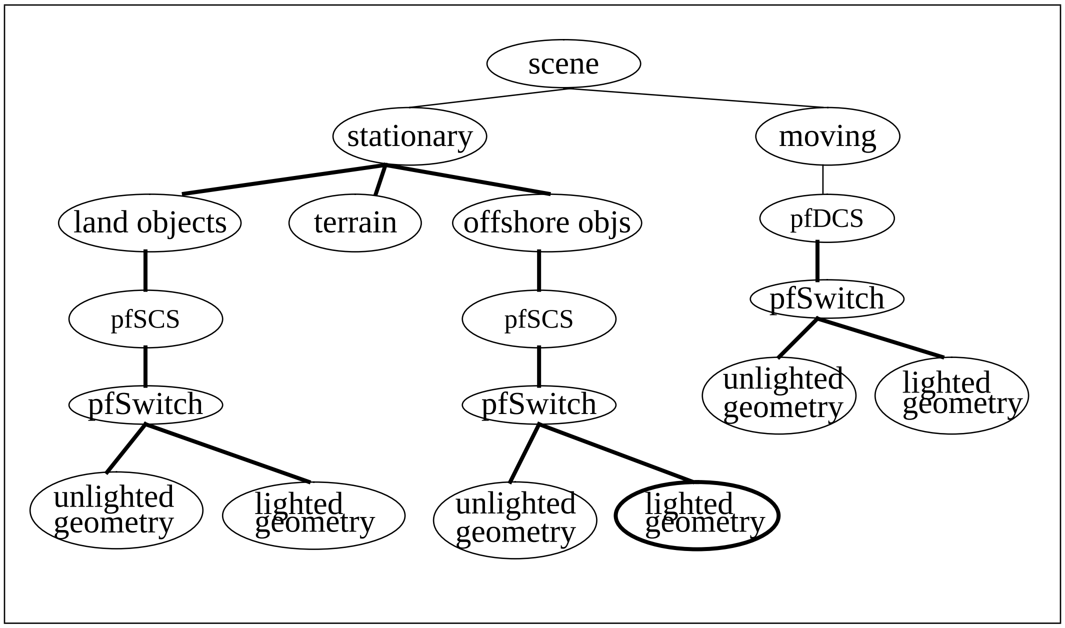


**Figure 10: Deployable Simulator Database Hierarchy**

## D. PROGRAM EXECUTION FLOW

The basic flow of the program (Figure 11) can be divided into six areas -- System initialization, run-time database (scene) construction, network initialization, real-time simulation loop and playback loop. System initialization consists of the Performer initialization process mentioned above. Network initialization involves preparing the simulation to both broadcast and receive ship entity information. Scene construction, also mentioned above, consists of loading the stationary and moving object geometry (in this case reading MultiGen flt files), adding the appropriate collision detection mask and adding it to the hierarchy (Figure 10). The remainder of this section will discuss the events within the real-time simulation loop and the playback loop.

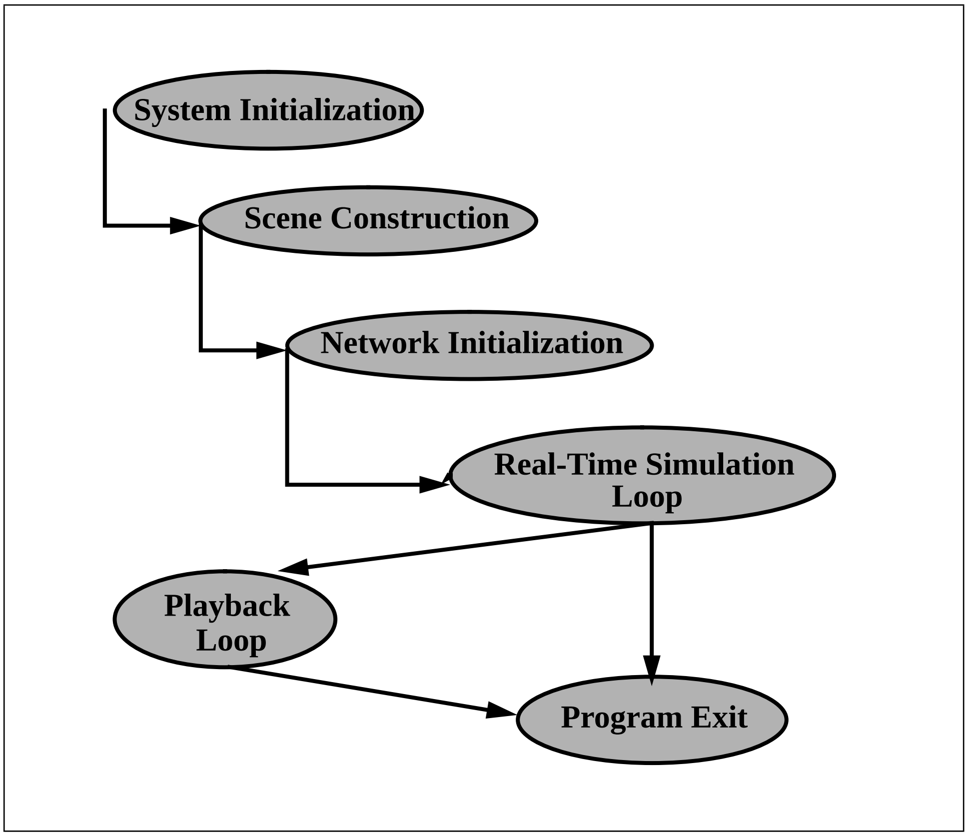


**Figure 11: Basic Program Flow**

### 1. Flow Within the Real-Time Simulation Loop

Within the real-time simulation loop, the simulation (application), cull and draw processes are continuously performed until playback is executed or the program is terminated (Figure 12). The application process is the sole process responsible for processing control inputs from the user, processing information received from the network, switching between lighted and unlighted geometry and determining and updating the states (position, orientation, velocity, course) of all ships in the scene. Application functions do not always occur prior to the cull and drawing processes. Control panel inputs, for example, need to be processed after the scene in which the control panel resides is drawn since manipulation of its functions occurs during the draw process. Therefore, the application process is split into two separate processes -- a preframe process which occurs prior to the cull and draw processes and a postframe process which occurs afterward.

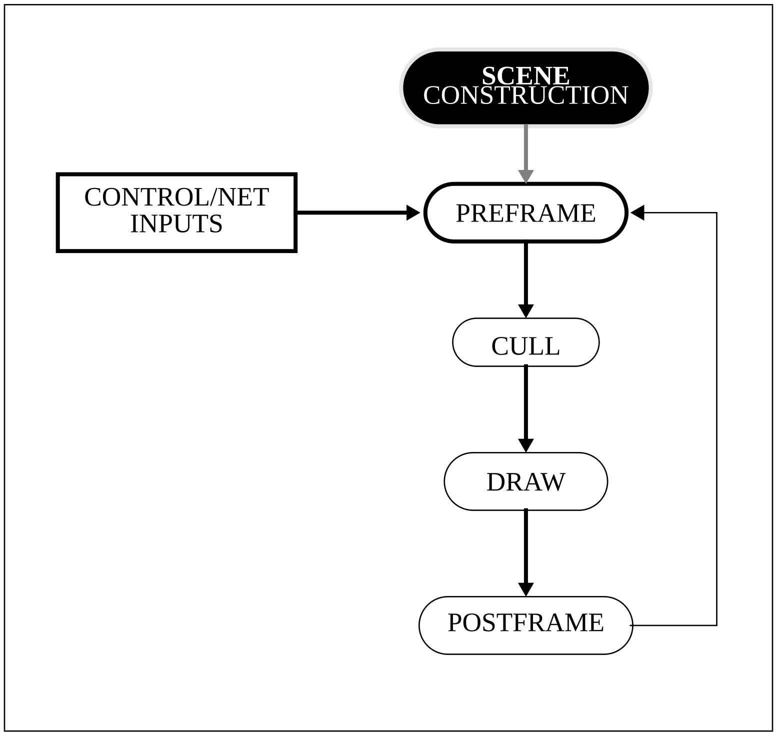


**Figure 12: Real-Time Simulation Loop**

### *a. Real-Time Preframe Process*

The preframe process (Figure 13) begins with reading the network to obtain DIS entity state protocol data units (PDU's) being broadcasted by other shiphandling simulators on the network. These particular PDU's contain information such as the identity (based on the network address of the transmitting station) and state (position, velocity, course and orientation) which are required in identifying who the ship is, where to place it within the scene and which direction and speed to move it until another position update is received. Only ship-type PDU's (DIS Domain_Surface) are processed. Once a PDU is received from another ship (not the one being driven), state information is obtained from the PDU and applied to that ship already in the scene. If a received PDU identifies a ship not currently in the scene, a new ship is created for that PDU and added to the scene. The

PDU reading process for a particular frame is completed when no more PDU’s are present for that particular frame. Following update of ship’s states received from the network, the driven ship’s state is updated and the geometry repositioned or moved within the scene based on the control panel settings (rudder angle, shaft RPM’s). To the user, the ship will appear smoothly transiting along the surface of the water. Once the driven ship is updated and moved, the remaining ships’ positions are updated by dead reckoning their new positions from either their last received position or their previously dead reckoned one. Dead reckoning involves applying the latest received velocity vector (along with a time step) to one of the positions above. In order to display the latest state information (that determined in the preframe process) of the driven ship on the screen, the state information just obtained is collected into a special package or data structure and then passed to the draw process for display in the tactical viewing area.

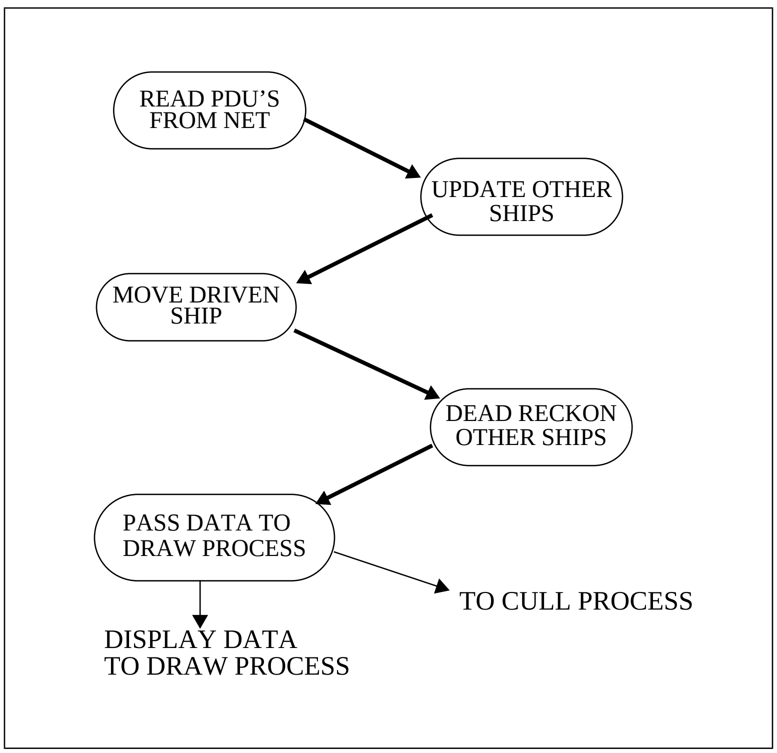


**Figure 13: Real-Time Simulation Preframe Process**

#### b. Postframe Process

The postframe process performs post drawing process administration such as the updating of global variables whose values depend on control panel settings. Control panel settings are then updated for the next time it is drawn. Environmental effects such as daylight and fog are also updated for the next frame.

### 2. Playback Loop

The playback loop (Figure 14) utilizes the same application, cull and draw processes as those of the real-time simulation loop. This was made possible through the sharing of a common main simulation loop within the program. The differences between real-time simulation and playback reside in the preframe process. With the real-time simulation, ships' states are updated via the control panel (rudder angle, shaft RPM's) for the driven ship and via the network for al the others. During playback, however, updates come from a script file generated during the real-time simulation. Playback can only be selected during the real-time simulation. Commencing playback in this manner allows the use of the same scene as that of the real-time simulation, thereby avoiding the necessity of reconstructing Additionally, the ships that were in the real-time simulation remain in the scene hierarchy and only need to be returned to their starting position. To prevent erroneous reporting of positions from the driven ship to other shiphandling simulators still running real-time exercises, the network is closed prior to beginning the playback.

#### a. Playback Preframe Process

The preframe process of the playback mode (Figure 18) begins with the reading in of state information pertaining to the legs or straight-line courses each ship travelled during real-time. The mechanism used by each ship, including the driven ship, for keeping track of its legs is an array of state information that was used during real-time. Each leg or row in the array is ordered either by the real-time PDU transmit times for the driven ship or arrival times of PDU's received from the others. For each ship, not all information

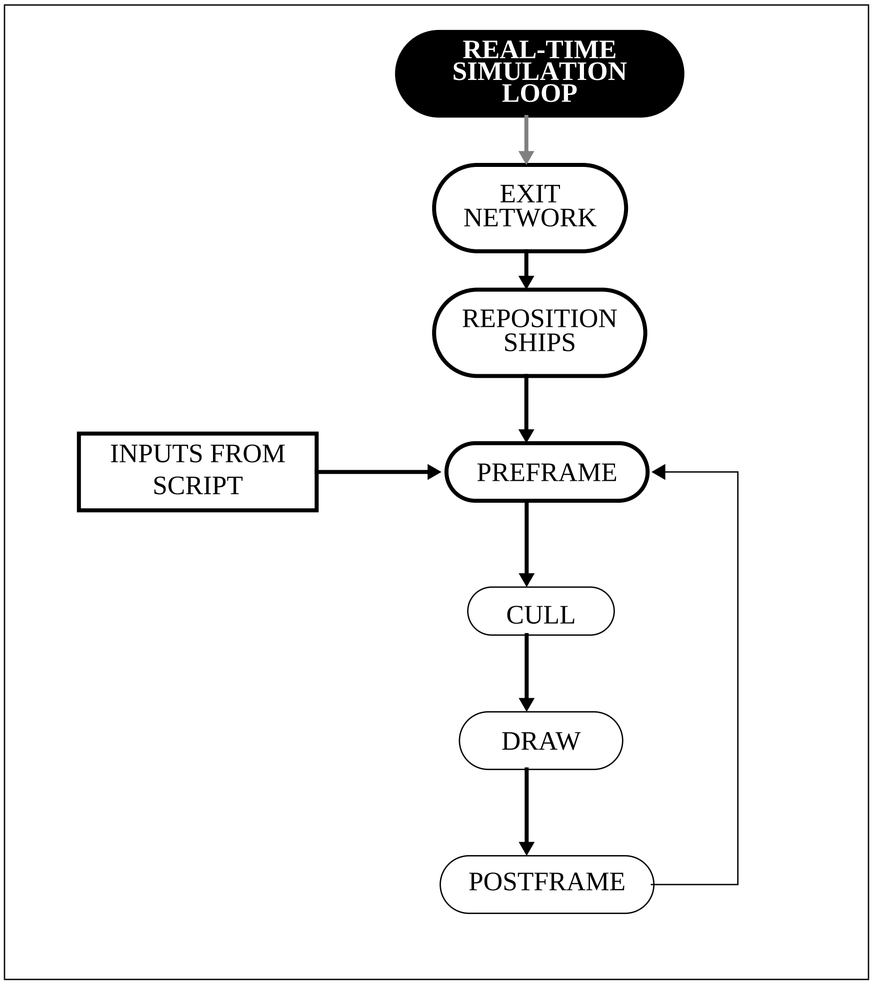


**Figure 14: Playback Loop**

contained in the script is entered into its playback array. To prevent the array from overflowing, only leg (or turnpoint) information meeting certain maneuvering criteria such as a two degree change in course or a five knot change in speed is added as a new leg. Once script file read and playback array construction is complete, a playback clock is initialized to the first time entry in the driven ship's playback array. Each ship is then started on its initial leg (provided it was moving at that particular time during the real-time simulation). Movement along a leg is performed by dead reckoning each ship between update positions in its playback array. During dead reckoning, the time of the next leg or turn is compared with the playback clock, which is incremented each time the preframe process is executed.

When the playback clock time goes above the turn time for a particular ship, the turn for that particular ship is executed. At turn time, a ship's state is updated similar to the way it is updated upon receipt of an entity state PDU from the network. In addition to state

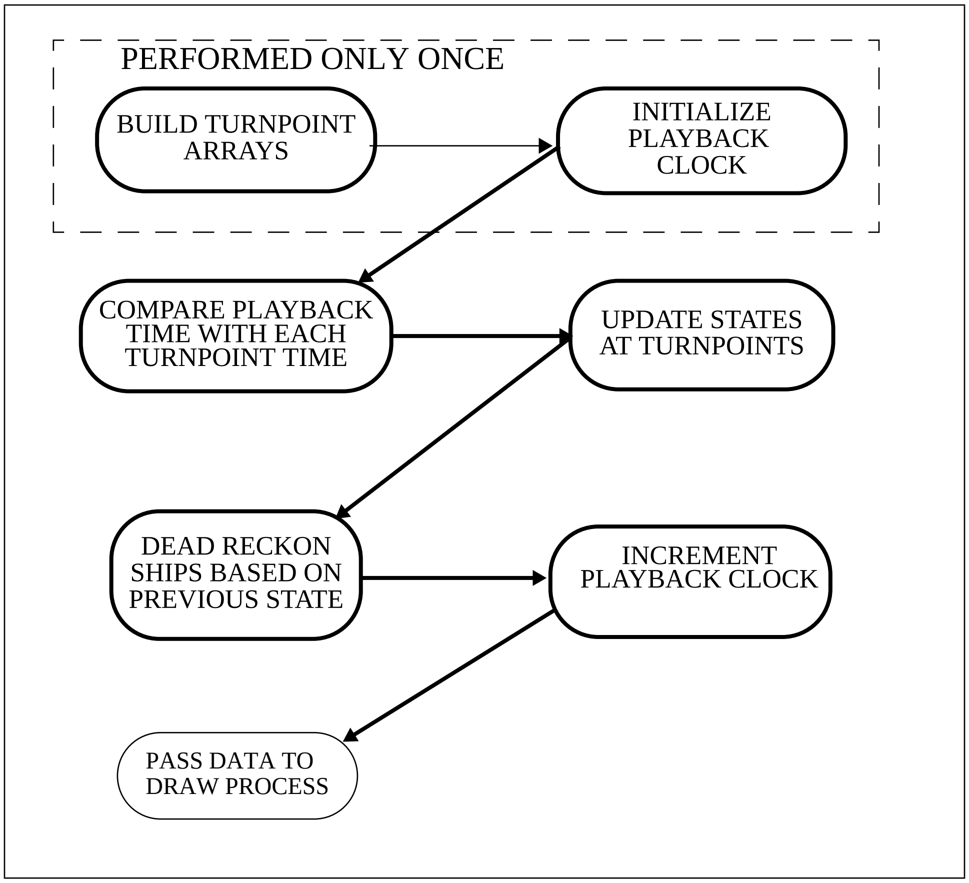


**Figure 15: Playback Prefame Process**

information being stored in the playback array, control information, mainly for the driven ship is also stored to show the particular settings on that leg. This information is passed to the draw process in the same manner as it is during the real-time simulation.

#### *b. Playback Postframe, Cull and Draw Processes*

The postframe, cull and draw processes for the playback loop are the same as those used in the real-time simulation loop.

## E. SUMMARY

IRIS Performer's multiprocessing and hierarchical run-time visual database (scene) features coupled with the high speed rendering and texture memory capabilities of the Reality Engine series workstations have given the portable shiphandling simulator the capability to process large, highly detailed visual databases while maintaining suitable frame rates to give the appearance of smooth motion as ships transit along the surface of the water. Additionally, adequate response to controls as well as no delay when changing views of the scene have also been made possible. Performance is also enhanced by constructing the scene hierarchy in a way such that collision detection with objects placed over land within the terrain database is ignored since ships generally run aground and halt before given the opportunity to collide with buildings. When transitioning from real-time simulation to playback, the scene remains intact, eliminating the need to reconstruct the scene as well as the ships that were a part of the real-time simulation. Playback also executes using the same execution or main simulation loop that the real-time simulation used, allowing most of the functionality that was present during the real-time simulation.

# V. HYDRODYNAMICS AND MANEUVERING

## A. RIGID-BODY SHIP DYNAMICS

### 1. Coordinate Systems

The movement of surface ships through the ocean is described in six different motions or *degrees of freedom*. To better understand the motion of a ship it is simpler to define two coordinate systems -- a moving or *body-fixed* coordinate system (here after referred to as body coordinate system (BCS)), that is attached to the ship and an earth-fixed or world coordinate system (WCS) which is attached to the world (or environment) the ship moves in. The WCS described is that implemented by IRIS Performer [SGI94]. Figure 19, illustrates these two coordinate systems.

#### *a. Body Coordinate System*

The origin of the BCS coincides with the center of gravity of the ship. Moreover, axes in the body coordinate system coincide with the *principle axes of inertia* of the ship defined as follows:

- Longitudinal axis - axis directed along the centerline from the bow to the stern of the ship
- Lateral or traverse axis - axis directed from the port beam to the starboard beam
- Vertical or normal axis - axis directed from bottom to top

#### *b. World Coordinate System*

The WCS is describe as a right-handed coordinate system with the origin located at an arbitrary point within the world. Axes within the world coordinate system are described as follows:

- X axis - Positive direction corresponds to East
- Y axis - Positive direction corresponds to North
- Z axis - Positive direction corresponds to increasing altitude

A ships position within the WCS is described in terms of its x,y,z coordinates. Additionally, the world coordinate system describes a ship's orientation using a series of Euler or rotation angles (Figure 16) with respect to the axes listed above.

- Pitch ($\theta$) - Rotation with respect to the x axis. Upward rotation denotes the positive direction
- Roll($\phi$) - Rotation with respect to the y axis. Counterclockwise rotation denotes the positive direction
- Yaw($\Psi$) - Rotation with respect to the z axis. Counterclockwise rotation denotes the positive direction. This angle also described as the ship's heading.

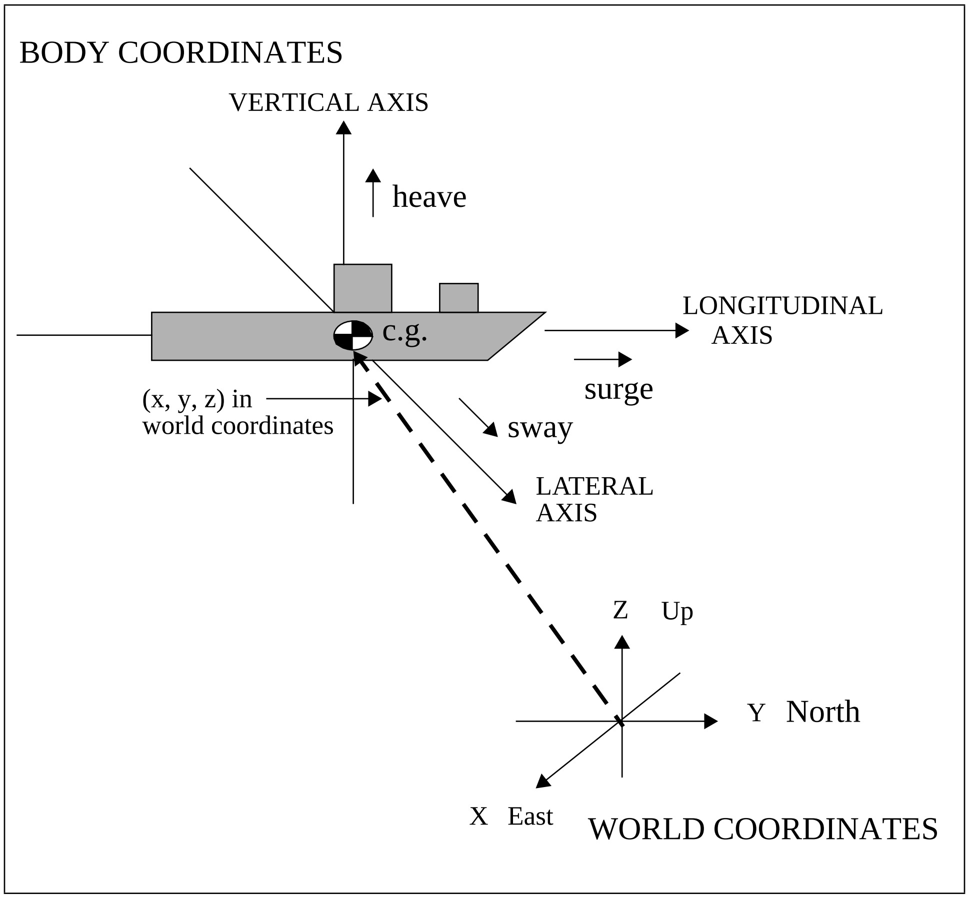


**Figure 16: Coordinate Systems [FOSS94]**

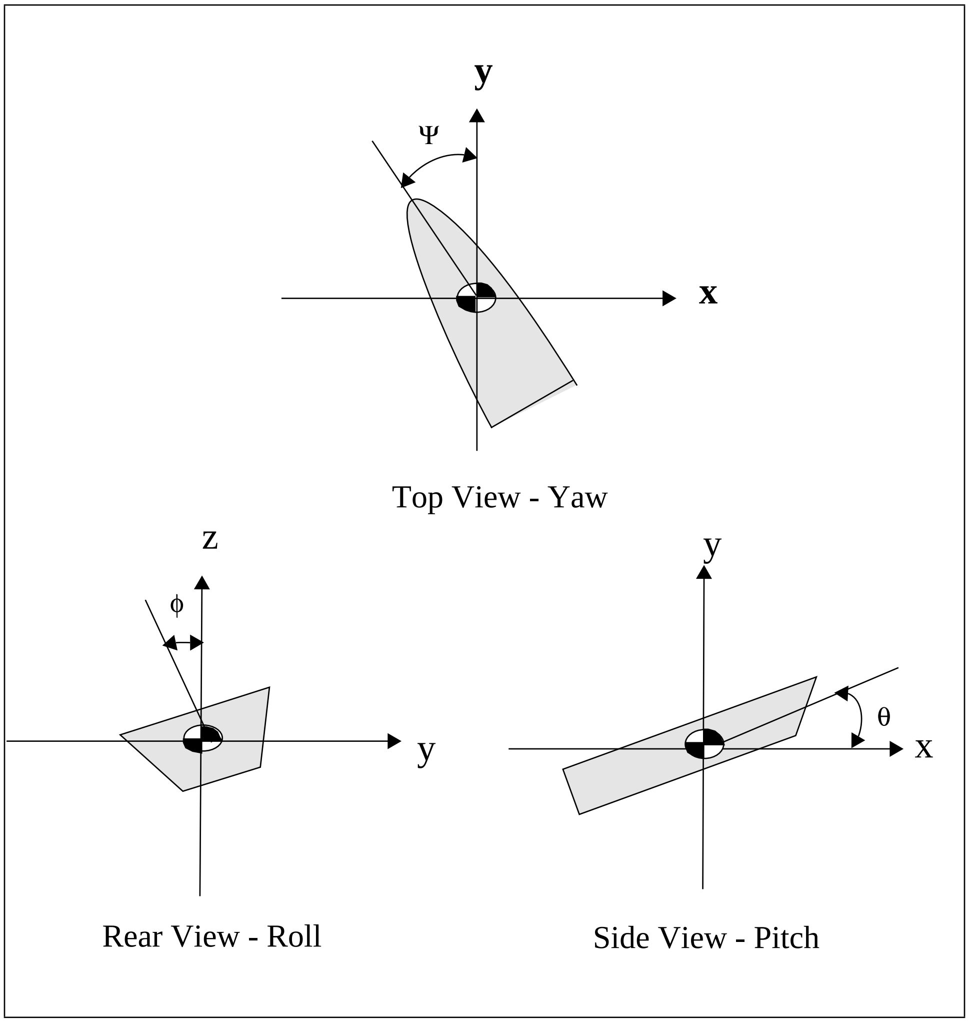


**Figure 17: Yaw, Pitch, and Roll Angles**

### 2. Motion in Six Degrees of Freedom

Within its six degrees of freedom, the motion of a ship can be described in terms of velocity within its body coordinate system. There are 6 different velocities -- three linear and three rotational. The linear velocities describe motion along the ship's three body coordinate axes -- *surge, sway,* and *heave* (Figure 17). Rotational velocities describe motion around these three axes *pitch rate, roll rate and yaw rate*. These six velocities possess the following characteristics:

- Surge - forward and backward velocity of a ship along its longitudinal or centerline axis.
- Sway - sideways velocity of a ship along its lateral axis
- Heave - up and down velocity along ship's vertical axis
- Roll rate - ship's rate of rotation along its longitudinal axis
- Pitch rate - ship's rate of rotation about its lateral axis
- Yaw rate - ship's rotation rate about its horizontal axis

## B. FORCES ACTING ON A SHIP

The movement of a ship is caused by forces acting upon its body coordinate system. These forces consist of external forces such as ocean current, prevailing winds and wave action (or sea-state). Internal forces are those forces generated by the ship's propulsion machinery (e.g. propellers, thrusters...etc.) and control surfaces (rudders). Internal and external forces can be further classified into three categories -- *controllable forces, semi-controllable forces* and *uncontrollable forces* [CREN77].

### 1. Controllable Forces

Controllable forces are described as those forces that can be controlled by the actions of the conning officer through the use of the ship's machinery (e.g. rudders and propellers). The ship's propellers generate thrust that moves the ship in either a forward or backward direction, while the rudder generates a component of the thrust, thereby creating a moment or torque about the center of gravity. The effect of this torque causes the aft end of the ship to swing either to the port (left) or starboard (right) side. It is these forces generated by the propeller/shaft combinations that must be understood to steer the ship and present a good training mechanism for the deployable simulator. Figures 18(a) through 18(h) show resultant forces generated by the various propeller thrust and rudder angle combinations. Table 10 describes the motions generated by these resultants.

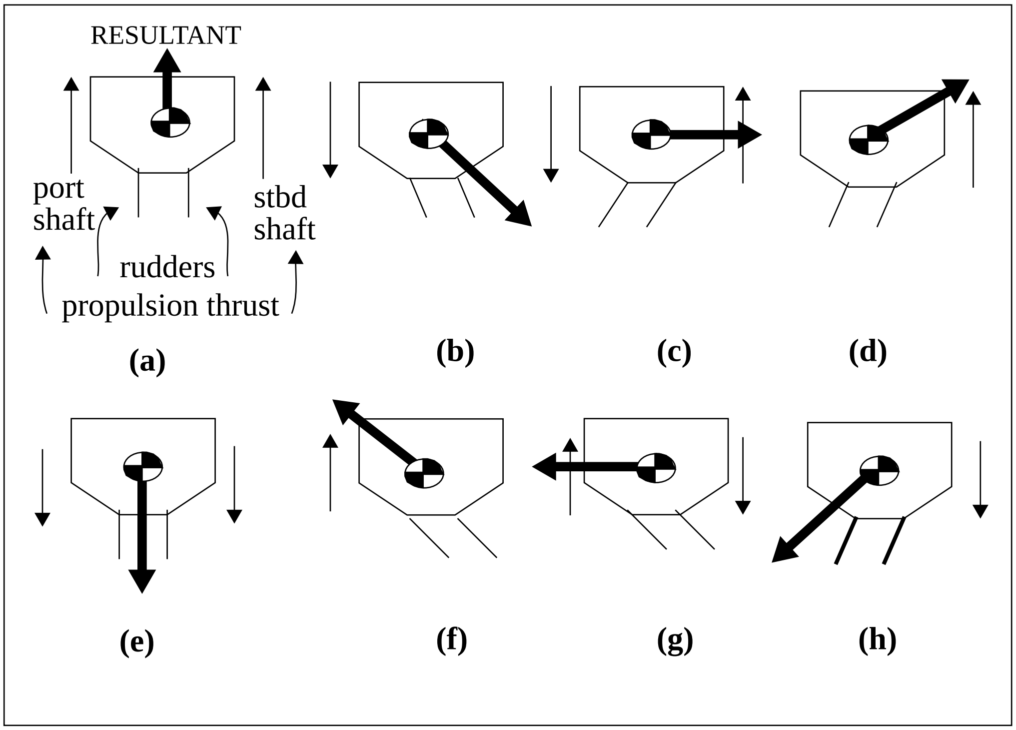


**Figure 18: Resultant Forces [CREN77]**

| Figure 19 Subhead | Rudder Deflection | Port Shaft | Starboard Shaft | Motion |
|---|---|---|---|---|
| a | None | Ahead | Ahead | Forward |
| b | Left | Back | None | Back to the right |
| c | Right | Back | Ahead | Right rotation |
| d | Right | None | Ahead | Right turn |
| e | None | Back | Back | Reverse |
| f | Left | Ahead | None | Left turn |
| g | Left | Ahead | Back | Left rotation |
| h | Right | None | Back | Back to the left |

**Table 10: Rudder/Shaft Combinations**

### 2. Semi-Controllable Forces

Semi-controllable forces are those forces that are generated by the surrounding area that the ship is located in. These forces are usually present in narrow waterways where thrust generated by the ship's propellers and the wake resulting from the ship's movement through the water cause the immediate surroundings of the waterway (e.g. sides, bottom...etc) to generate repelling forces which act against the ship. The conning officer can regulate these forces using the proper controllable forces [MSI93].

### 3. Uncontrollable Forces

Uncontrollable forces are those caused by nature such as winds, currents and sea-states. Conning officers have no control over these forces but must either compensate for them or use them to their advantage [MSI93].

## C. HYDRODYNAMICS MODELS

### 1. Description of Current Models

Several hydrodynamics models have been developed to simulate the reactions of a ship to internal and external forces including the models of Fossen [FOSS94] and Brutzman [BRUT94]. These hydrodynamics models involve the use of physically-based equations of motion to simulate motion of their respective vehicles resulting from these forces. These equations involve intense mathematical calculations consisting of several matrix multiplications and trigonometric functions.

Each model uses the vehicle's mass, length, mass moment of inertia, thrust from propulsion and the settings of control surfaces (rudders) to calculate the resultant controllable forces. Additionally, the semi-controllable and uncontrollable forces are also included. In the Brutzman [BRUT94] and Fossen[FOSS94] models, the total force is represented as a six by one matrix. Vehicle masses (including mass moments of inertia) are represented by six by six matrices known as mass matrices. Changes in the position and orientation (when combined describe the posture) of a vehicle or its motion are determined using two Euler numeric integrations applied to Newton's Second Law of Motion (Eq 5.1). The first step in obtaining a new posture resulting from the various forces is to find the acceleration matrix. Acceleration is determined by multiplying both sides of Eq 5.1 by the mass inverse matrix ($[M]^{-1}$) to give Eq. 5.2. Next, the velocity matrix which contains all of the velocities (surge, sway, heave, pitch rate, roll rate and yaw rate) is determined by applying the first Euler integration to Eq 5.2 with a time increment, dt to give Eq 5.3. Up to this point, all forces, accelerations and velocities are expressed in the vehicle's body coordinate system. Changes in position and orientation within the world coordinate system are determined by first converting the velocity matrix [V] to a world coordinate velocity and performing the final Euler integration with respect to the same time increment. The change in posture may they be applied to the current posture to obtain the new posture (Eq 5.4).

$$[F] = [M] \cdot [A] \tag{Eq 5.1}$$

$$[A] = [M^{-1}] \cdot [F] \tag{Eq 5.2}$$

$$[V] = [A] \cdot dt \tag{Eq 5.3}$$

$$[\text{NEW POSTURE}] = [\text{CURRENT POSTURE}] + [V] \cdot dt \tag{Eq 5.4}$$

### 2. Applying Existing Equations of Motion to the Deployable Shiphandling Simulator

The deployable shiphandling simulator initially implemented modified versions of the AUV's equations of motion utilizing hydrodynamics coefficients for a specific ship type (i.e. Ticonderoga class cruiser). Consequently, the use of these equations caused a dramatic reduction in rendering speeds for the simulation from the desired fifteen frames per second to four point five frames per second. The slower frame rates were due to the additional time the application process required to complete the hydrodynamics calculations.

## D. DEPLOYABLE SIMULATOR RIGID BODY DYNAMICS

### 1. Assumptions

Prior to developing a hydrodynamics model for the deployable shiphandling simulator, the characteristics of the real environment that the simulator represents were examined to determine which behavioral characteristics of the ship such as sway and heave could be eliminated with the absence of certain uncontrollable and semi-controllable forces such as high winds and large waves in the operating environment. The results of this analysis determined that the ship would be operating in calm seas and that heave and sway action could be considered negligible. Moreover, for the exercise being supported (entry into San Francisco Bay), a ship would require fairly smooth seas since ships normally do not enter port in rough seas.

### 2. Objectives

The objectives in developing the simple hydrodynamics model were to provide some of the physical ship handling characteristics such as tactical diameter that conning officers are familiar with while maintaining an adequate rendering performance. Also desired was the ability to control forward and backward thrust using the speed of the propeller shaft as input. Additionally, the propeller shafts would a need the abilities to act independently to allow controlling the direction of the ship using engines alone or to allow tighter turning or twisting of the ship. A means of controlling the direction of the ship using rudder angle inputs in degrees would also needed.

### 3. Development of Simple Hydrodynamics Model

The ship in the deployable simulator is considered a physically based model of the ship it represents -- it has mass (derived from weight), it has two propellers that are located laterally a fixed distance from the centerline to propel it and it has a rudder located longitudinally a fixed distance from the centerline to turn it. Using these characteristics, the simple hydrodynamics model was developed.

### *a. Linear Motion*

With the absence of the sway, heave, pitch and roll components of the ship's motion, the forward and backward translational motion of the ship is restricted to the longitudinal axis of its body coordinate system. Therefore, the acceleration and velocity values within the body coordinate system could be treated as scalars instead of matrices. With this in mind, multiple matrix multiplications are avoided when only scaler quantities are applied to Newton's Second Law of Motion (Eq 5.5) [SEAR79]. As with the more complex models listed above, acceleration (in body coordinates) could be derived by dividing both sides of Eq. 5.5 by the mass, $m$, of the ship to give Eq 5.6. The force in these equations refers to the total thrust of each propeller (Eq 5.7). Thrust from each propeller is obtained by multiplying the shaft speed (in RPM's) by a constant (in Newtons/RPM) (Eq 5.8). Using an Euler numeric integration of the right side of Eq 5.6 with time increment dt, the velocity, $V$, can be obtained (Eq 5.9). Prior to moving the ship within the world coordinate system, the velocity must be "oriented" in the world coordinate system. When this occurs, the velocity becomes a vector since the ship's longitudinal axis may not coincide with the y axis of the world coordinate system (in other words, the ship may be traveling in other directions besides North). With the world coordinate velocity, an additional Euler integration is performed to obtain a change in the x, y and z world coordinates. Adding this change to the previous world coordinate position, a new position (in world coordinates) is returned (Eq 5.4).

$$F = m \cdot a \qquad \text{(Eq 5.5)}$$

$$a = F/m \qquad \text{(Eq 5.6)}$$

$$\text{F = TOTAL THRUST = THRUST}_{\text{Port prop}} + \text{THRUST}_{\text{Stbd prop}} \qquad \text{(Eq 5.7)}$$

$$\text{THRUST = CONSTANT(NEWTONS/RPM) x RPM'S} \qquad \text{(Eq 5.8)}$$

$$V = dt \cdot (F/m) \qquad \text{(Eq 5.9)}$$

*b. Angular motion*

The angular or yaw motion of the ship is the result of moments or torques acting on the ship's center of gravity. These torques are generated by the rudder when deflected to turn the ship or by asymmetric thrust resulting from differences in speed between shafts when operating in a split shaft configuration. A torque ($\Gamma$) or twisting force, is defined as force times the distance ($l$) to the point that the moment is acting on (Eq 5.10) which is in this case the center of gravity of the ship [SEAR79].

$$\Gamma = F \cdot l \qquad \text{(Eq 5.10)}$$

The torques caused by thrust generated by the shafts($\Gamma_{PORT\ SHAFT}$ and $\Gamma_{STBD\ SHAFT}$) are determined by multiplying the thrust generated by the shaft times the shaft's lateral distance (l) to the center of gravity. Forces located to the left of centerline that generate torque in the clockwise direction (Figure 19) are considered negative in sign. Forces located right of centerline have the same effect except the torque is in the counterclockwise direction. If both propeller thrusts are equal, the corresponding torques generated by each of them cancel, resulting in forward motion without twist.

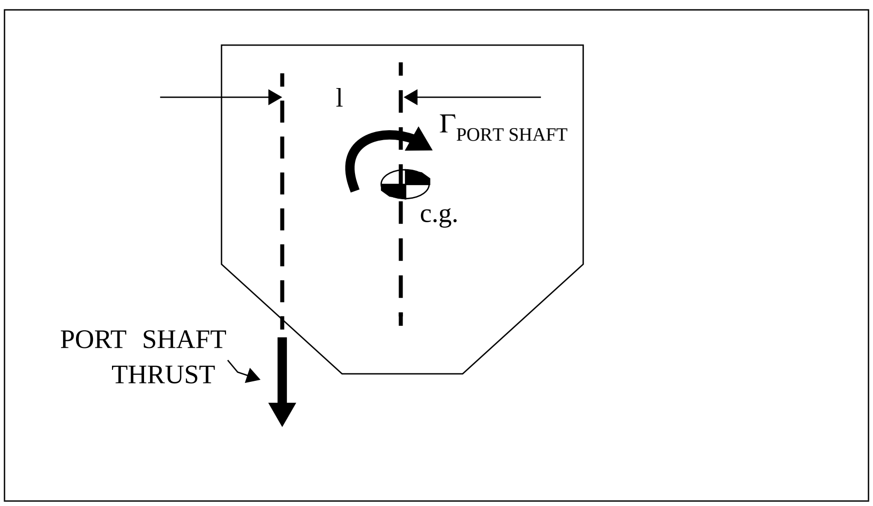


**Figure 19: Clockwise Torque Due to Port Shaft**

The rudder angle has the greatest effect on the total torque of the ship. When deflected a desired angle, the thrust from the propeller causes the rudder to generate a component force which produces a torque ($\Gamma_{RUDDER}$) that points the bow of the ship in the desired direction. For the rudder angle, the distance (l) used to obtain torque is the longitudinal distance between the rudder and the ship's center of gravity (Figure 20).

The total torque on the centerline of the ship($\Gamma_{TOTAL}$) is determined by adding together the torques resulting from the shafts and the torque generated by the rudder (Eq 5.11). To calculate the torque generated by the rudder (Eq 5.12), the thrust component that it generates is first determined by multiplying one of the shaft thrusts by the rudder deflection angle ($\theta$). Rudder angle values using left rudder are negative. When multiplied by a positive thrust value, a negative torque is generated causing the ship to twist left (provided the torques from the shaft cancel one another). Right rudder deflection angle values are positive, resulting in positive torques steering the ship to the right.

$$\Gamma_{TOTAL} = \Gamma_{RUDDER} + \Gamma_{STBD\ SHAFT} + \Gamma_{PORT\ SHAFT} \qquad \text{(Eq 5.11)}$$

$$\Gamma_{RUDDER} = THRUST \cdot \sin\theta \qquad \text{(Eq 5.12)}$$

With the total torque determined, it is now possible to determine how much to change the current yaw with respect to the ship's vertical axis and how fast the torque is causing the ship to turn. To determine this, Newton's Second Law of Motion with respect to rotation is used (Eq 5.13). With this law, torque is determined by multiplying a rigid body's *moment of inertia* ($I$) by the angular acceleration with which it is rotating ($\alpha$). Since total torque has been determined from Eq 5.11, the angular acceleration can be determined by dividing both sides of Eq 5.13 by the moment of inertia resulting in Eq 5.14. Integrating angular acceleration with respect to time, $dt$ (in this case using an Euler integration with a time increment), the angular velocity ($\omega$) for that time can be obtained (Eq 5.15). Integrating angular velocity with respect to time, $dt$, the change in yaw or heading is obtained and when added to the previous heading, will give the new heading (Eq 5.16).

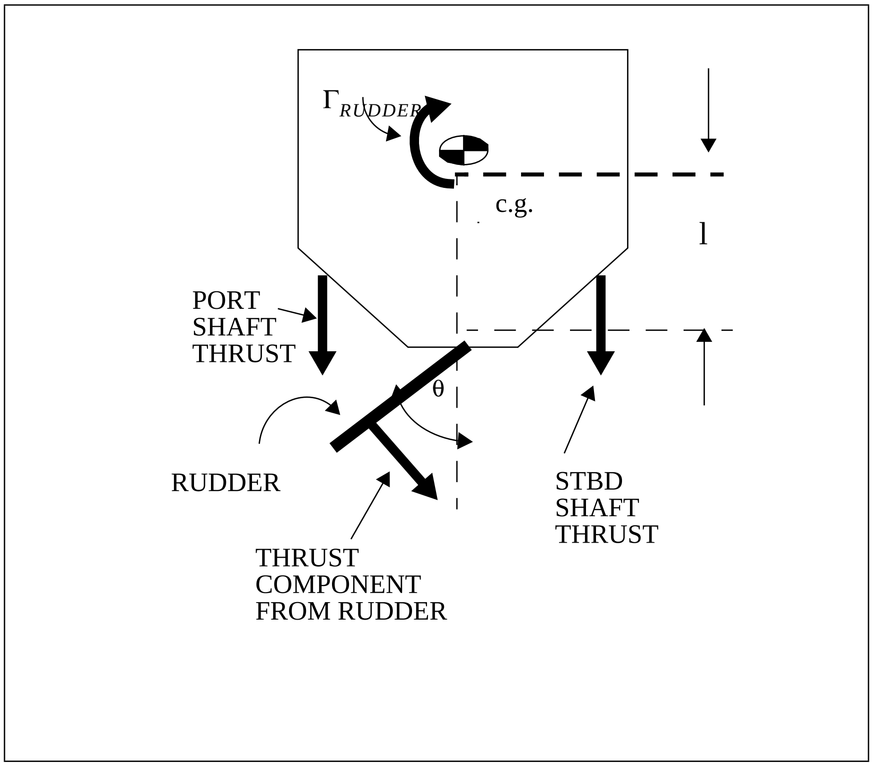


**Figure 20: Torque Generated from the Rudder**

If no torque is present (no asymmetric thrust nor rudder deflection), the heading remains the same.

$$\Gamma = I \cdot \alpha \qquad \text{(Eq 5.13)}$$

$$\alpha = \Gamma / I \qquad \text{(Eq 5.14)}$$

$$\omega = \alpha \cdot dt \qquad \text{(Eq 5.15)}$$

$$\text{NEW HEADING} = \text{OLD HEADING} + \omega \cdot dt \qquad \text{(Eq 5.16)}$$

### *c. Performance Results*

The rendering performance of the deployable shiphandling simulator utilizing the simple hydrodynamics model was dramatically improved in overall rendering times with a great decrease in processing time required over the more accurate, complex ones mentioned above. Table 11 gives a comparison between the AUV model and the simpler one developed when applied to the deployable shiphandling simulator (single workstation). The AUV model, is by far the most accurate and the most flexible, taking into consideration all the forces acting upon a vehicle and all the vehicle's behavior to these

| Hydrodynamic Model | Best speed (frames per second) | Worst speed (frames per second) |
|---|---|---|
| AUV Model | 4.5 | 1 |
| Simple Model | 30 | 9.0 |

**Table 11: Rendering Performance of Hydrodynamics Models**

forces whether it be a submersible, such as the case with the AUV, or a surface ship. As far as the realism or "feel" of the virtual ship's motion, the handling characteristics such as the tactical diameter of real ship's is classified and is above the classification of this thesis. However, when demonstrated to experienced ship's conning officers, their feedback as to the realism of handling was positive.

## E. SUMMARY

The hydrodynamic characteristics a ship are difficult and complex to model since a ship is free to move in six degrees of freedom. Even in a full-scale simulator, there are dedicated processors devoted specifically to performing these large and complex computations. For the deployable shiphandling simulator, such a complex model was initially implemented but tended to slow the simulation down to a point where the motion of the ship was either too slow or did not exist. To add motion to the ship, a simpler hydrodynamics model was derived assuming that the ship would be operating in calm seas (such as a harbor entry scenario) which is normally the training scenario for beginning conning officers. Furthermore, eliminating some of the effects that would not be found in the scenario such as pitch, roll, sway and heave allowed simpler equations of motion to be derived to simulate the motion of the ship. The maneuvering behavior of the ship in the scenario appears similar to that of a real ship as noted by experienced conning officers.

# VI. MULTIGEN: A DYNAMIC 3D MODELING TOOL

The design and development of the deployable shiphandling simulator's database and all of its associated models were created with a most formidable three dimensional, interactive modeling tools, used in creating visual simulation systems. We felt it befitting that it receive some mention of its robust capabilities. MultiGen was implemented to support a number of different visual systems. Each implementation contains a common user interface plus the software subsystem that supports the visual platform, known as the Database Logic, or DBL   MultiGen Flight is a version of MultiGen that supports Software Systems' Flight database format, designed for general purpose image generator support.

Its use was quite extensive and it is rapidly becoming one of two standard modeling application tools for students here at the Naval Postgraduate School.

## A. GRAPHICAL OBJECT MODELING TOOLS

Briefly stated modeling is the creation of graphical objects. Throughout our research, we found it to be extremely tedious, complex, and time consuming. Ironically, we were warned at the outset of this by one of our advisors.

One important design issue we failed to consider early on during the planning phase of our research was that of choosing a modeling tool or subsystem which addressed ease of construction [AIRE90]. In the case with our project, our research was unfunded, leaving us with few alternatives. However, we learned later on that there was perhaps a good way to characterize or classify, and evaluate graphical modeling systems for use in thesis research. We feel that these findings along with the techniques we used will benefit others conducting similar graphical research in the future.

Very briefly, we learned that research had been previously performed at Harvard University by Kochhar, Marks, and Friedell which provides a comparative description of human-computer cooperative interaction paradigms for creating graphical objects. Their work served three purposes: (1) It presented a conceptual framework for organizing known paradigms; (2) It provided a basis for choosing among the set of existing paradigms; and

(3) It exposed opportunities for developing new interaction paradigms with certain combinations of characteristics.

Their research classified existing interaction paradigms for graphical-object modeling into six categories, organized with respect to what they termed as their principal organizational characteristics, Figure 21.

Existing Interaction Paradigms

Fully Manual

Constraint-Based

Critic-Based

Inprover-Based

Fully Automated

CCAD (Cooperative CAD)

**Figure 21: Existing Interaction Paradigms**

In the case with MultiGen, we were faced with using what is classified as a critic-based modeling application [KOCH91]. As we found out later, such a system required us to perform the entire modeling task manually and allowed for critics to identify flaws in design and articulation, but remedies still had to be applied by us (the human collaborators). These characteristics although by no means are to be misconstrued as being a negative evaluation on MultiGen, however, for the time constrains associated with our research, they proved over in the long run, to be a major time sump for our limited and often scarce man-hours.

## B. 3-D MODELING

Creating a 3-D image of a design is one of the most exciting applications of computer graphics. It is relatively easy to take X, Y, Z data and create a wireframe perspective drawing (rendering) from any viewpoint. This can be quite useful in creating a model(s) of buildings, or ships and putting these models into an exciting or envisaged environment, and assessing its visual impact. Taking this visualization further, a lot of software has recently become capable in allowing 3-D building of models (e.g Open GL, Inventor). However, the process can be quite laborious and time consuming

For a modeling application to be a viable tool in today's rapidly growing world of computer graphics, it must possess one very important feature in order to reduce the overall modeling development process -- that being it must address the concept of "ease of construction" [AIRE90]. Failure to fulfill this most important concept will certainly lessen its chances for becoming a worthy tool for wide spread use by simulation database designers and developers. In MultiGen, we have made use of one of the premier modeling subsystems to create a myriad of three dimensional models which enhance the visual fidelity and truly enhance the appeal and immersive qualities of our database.In this chapter, we discuss some of MultiGen's formidable features which contributed to the overall development of the numerous models, entities, materials, conversion of raw DMA terrain data (both DTED and DFAD) into a three dimensional terrain database and most importantly its handling of levels of detail, texture application tools, and color/material application functions.MultiGen Basics

### 1. Introduction

MultiGen uses geometry, hierarchy, and attributes to describe objects in three dimensions. The geometry is a set of coordinate points like those used to model the box below in Figure 22. Each corner, or vertex, has an identification (v1, v2,...) and a coordinate value. The distances between pairs of vertices define the edges of the box. Sets of vertices which belong to the same side of the box are grouped into polygons, or faces, and the faces which make up the box are grouped into one box object. A database can contain one or many such models..

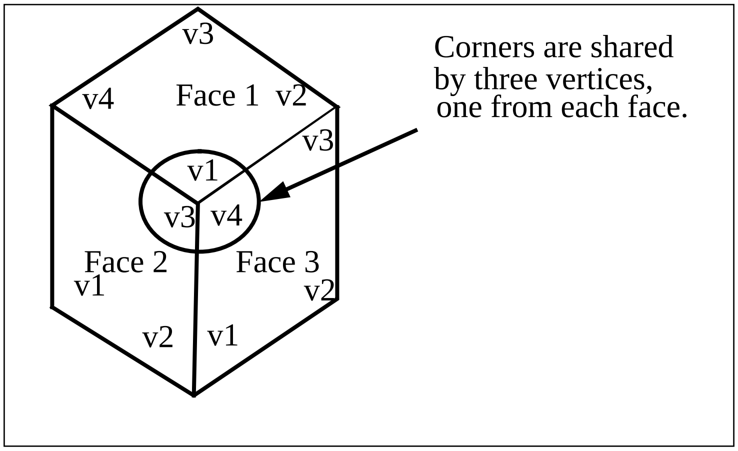


**Figure 22: A Box's Geometry**

The relationships between objects, faces, and vertices in the box define its hierarchy (Figure 23). Each element of the hierarchy is referred to as a bead. The parent of a bead is the place where it is attached to the hierarchy. Beads attached to the same parent are said to be children, at the same level in the hierarchy. The sibling which appears to the right of a bead in the hierarchy display is considered its next bead; the one drawn to its left is called the previous bead. Occasionally beads may be orphans, which are neither attached to the database nor saved with it.

### 2. MultiGen's Flight Data Format

Flight is a proprietary data format designed to meet the needs of the general purpose image generator. Its development process requires that all databases created be in floating point format, thus, any databases created in integer format will be automatically converted to floating point.

MultiGen is a modeling tool for creating and editing Flight format visual databases. As stated earlier, the structural elements of a Flight database are referred to as beads. There are several basic bead types that should be considered and once explained, will provide a

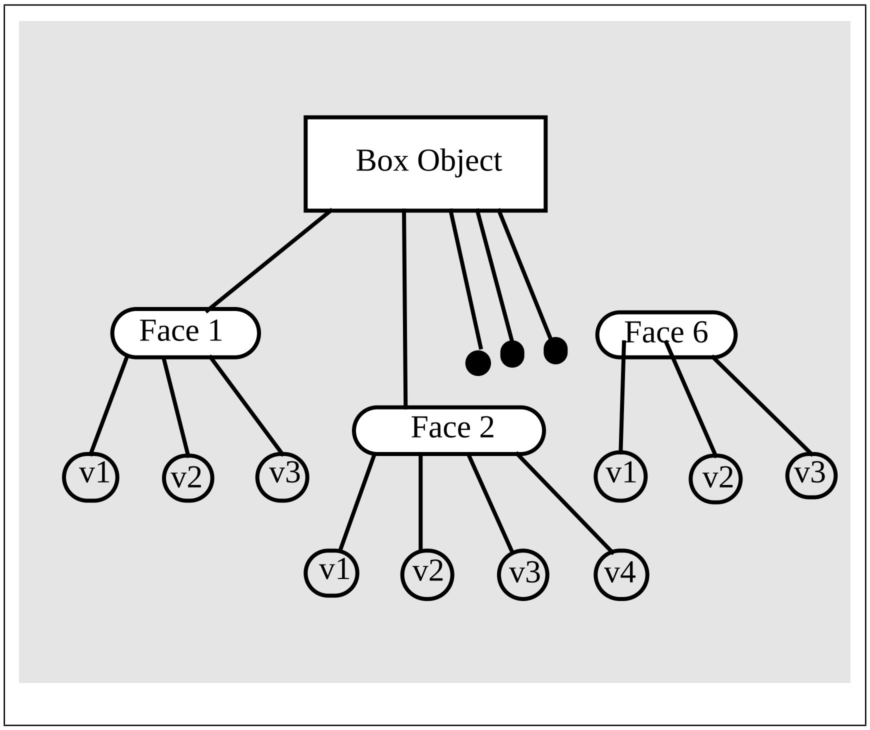


**Figure 23: A Box's Hierarchy**

better insight into the overall organization and methodology in which of the way each database is designed. Throughout this chapter, only a brief treatment or description will be provided. Any further explanation desired can be thoroughly explained in the MultiGen Modeler's Guide version 14.1[MULT94].

## C. THE FLIGHT DATABASE HIERARCHY

Flight is organized into a hierarchy which defines relationships between items in the database. A databases's hierarchy can be viewed in the hierarchy display window. A Bead is a generic term for items at any level of the database hierarchy. As a design consideration, it is always best to layout the design beforehand whether on paper or in the designer's mind before any work is done, the concept of object must be clear. This enhance both the interface with the system as well as allows for review of the database during the development cycle for inconsistencies and flaws.

MultiGen's tree-like structure contains all of the transformations and geometry to render a 3D graphics image. These structures have downward inheritance from parent to sibling for transformation purposes[YOUN93]. A similar arrangement is found in the Performer database structure. In Figure, several basic structures are displayed in our hierarchical structure of the model of the Golden Gate Bridge. We will describe each of these as they apply to the overall structure of our subject model.

**1. Database (DB) Header**

The top-level or root of the database is referred to as the Database (DB) Header bead. This bead is created automatically MultiGen for each new file. It provides some basic information such as database units, positional data relative to the earth's coordinates, and the date and time of the last update. The only type of bead that can be attached to it is that of the Group bead. One or more Group beads can be attached at any one time. DB beads are color coded black.

**2. Group Beads**

A Group bead is the highest level in the hierarchy that a modeler can create. Under normal circumstances, the entire database can be attached to a single group bead just below the DB bead. It can contain a transformation matrix which is applied to all of its descendant beads and is the lowest level at which an animated sequence, external reference, or replication can be started. These group beads can have other group beads, LOD beads, or object beads attached to them as children. As depicted in Figure 24, the first (or master group) bead is labeled as BRIDGE. Group beads are generally color coded red.

Additionally, attached below the LOD beads shown, are several other Group beads which can be referred to as SubGroup beads. Their names represent those groups of objects attached as children to each of the subgroup beads. An explanation of each is as follows:

- Tower - The bridge towers located at both the North and South ends of the bay.
- Roadway - The pavement or roadway on the bridge.
- Support - The roadway support cables.

• Pylons - Roadway pylons which support the pavement.

• Lites - Lites which illuminate the bridge.

### 3. Levels of Detail

So as to remain in a logical order of progression, the next bead that can be created by the modeler is that of the Level-Of-Detail (LOD). LOD models are only displayed within a predetermined range from the eyepoint. This allows the image generator to make objects appear increasingly complex as the eyepoint approaches by replacing a low resolution model stored under one LOD with a higher resolution model stored under another LOD.

At long distances, an object can be represented by fewer polygons, and as it gets closer to the viewing point, more polygons can be added for detail. Only group and object beads can be added to an LOD bead.

Each bead contains a switch-in and switch-out distance field which determines the visual range and center coordinate. If the distance from the eyepoint to the LOD center falls outside of this range, the node is excluded from the display list as the database is culled. LOD beads can be used in two different ways. The ranges of two LOD beads can be overlapped, or their ranges can follow each other in sequential manner[PRAT93].

LODs with overlapping ranges, more commonly called additive LODs, allow the basic shape of the object to be put into a low resolution model and each progressive level adds more geometry to the icon. This technique is good for adding such details as bridge support cabling, lights, and suspension ropes. In the case of the hierarchial structure for the Golden Gate Bridge (Figure 27), there are five LODs attached to the BRIDGE Group bead. LOD beads are color coded blue. As stated earlier we will provide a more detailed discussion of this application later in this chapter.

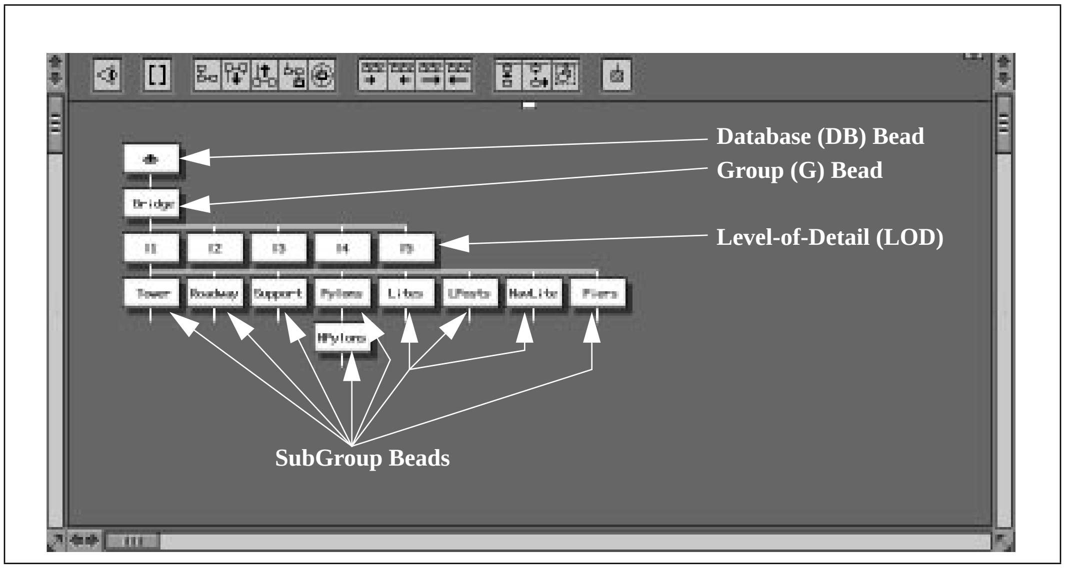


**Figure 24: Flight Database Hierarchy Structure**

### 4. Object Beads

The next significant bead in the hierarchal structure is the Object bead. This bead contains a number of polygons that are related in some manner. For example, in Figure 25 (below) by tracing the tree down to the Bridge group and then right to Pylons Group Bead, then a downward traversal of the tree to the NPylons bead (this is the subgroup for the North Pylons), you will notice to the immediate right, the associated Object beads for the Pylons. The choice and selection of the names and numbers of object beads are clearly a design issue for the developer of any visual simulation system.

### 5. Polygons

Polygon (P) Beads are simply a collection of ordered, coplanar vertices describing a surface. Polygons have a color associated with them which generally corresponds to the color of the face, and a forward facing direction such that vertices are ordered in a counterclockwise direction when viewed from the forward side. They can be considered as describing a recognized primitive of MultiGen. Faces can be a point if it has one vertex, a line if it has two vertices, or a polygon if it has three or more vertices. If the polygon bead

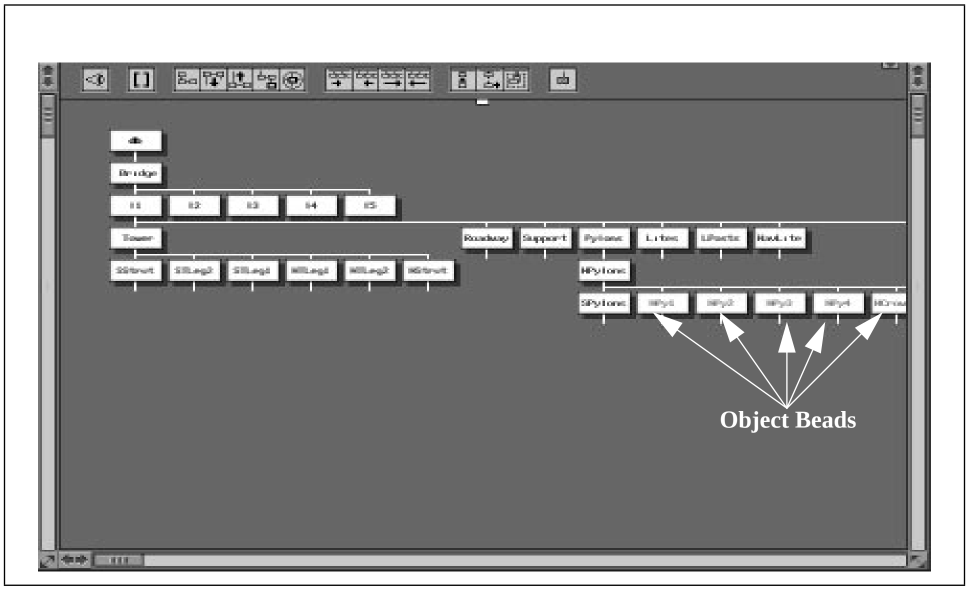


**Figure 25: Flight Database Hierarchy Structure**

defines a polygon, then it will also contain the normal for the polygon, texture coordinates, and the color and material for the polygon. Polygon beads can be attached to object beads, or to other polygon beads as a coplanar subface. Polygons should be made convex and planar to ensure the graphics hardware can render them efficiently. (See the MultiGen Modeler's guide for more information.)

Displayed in Figure 26, we see the Group Bead (Piers) as the root bead and attached directly below, we see a subGroup Bead of SPierCt (which is the abbreviation for South Pier Center). Also at the Object Level, we notice the Object Bead (o258) serving as the parent bead to several lower level Polygon Beads (numbers p2992 thorough p3002). As mentioned earlier Polygon Beads possess their own color code which is unique to the respective bead.

The previous basic concepts are key to understanding the inner workings of the MultiGen package and most importantly for assisting any potential designer and developer of three dimensional models being created for virtual environment use.

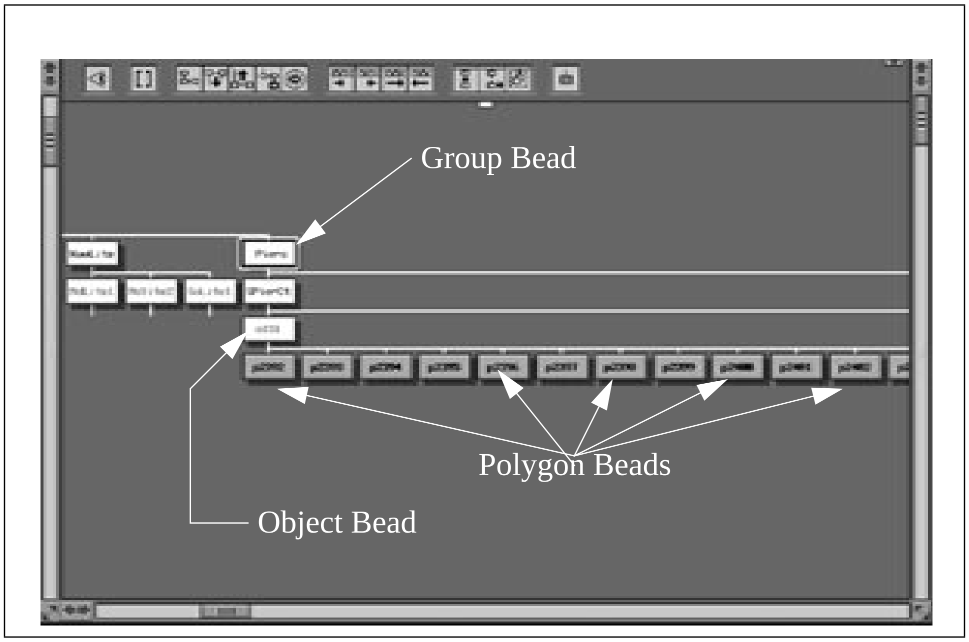


**Figure 26: Flight Database Hierarchy**

## D. MULTIGEN'S DMA OPTION

One of MultiGen's most unique features and perhaps the one most used by us in the early stages of our research, was that of the *DMA Option.* In this portion of the chapter, we will once again take the same approach of providing a brief background on the basics of this particular feature and later on discuss how we used it to complete our research project.

The basics of the MultiGen package were briefly discussed above, however, the DMA option presented a whole new approach for us with respect to the conversion of raw DTED and DFAD data into a working three dimensional terrain model for our simulation database.

There are three basic components associated with the DMA option. As shown in Figure 27. They are:

- The Terrain Option - Converts various types of gridded post terrain data into polygonal databases that can be edited and saved for display on image generators.
- The Cultural Option - Imports cultural data (roads, buildings, rivers, etc.) into MultiGen for projection into a polygonal terrain database.
- The Area Block Processing Option - Lets the user process large amounts of terrain

and cultural data in semi-automated mode. It also provides the ability to read data from a compact disk.

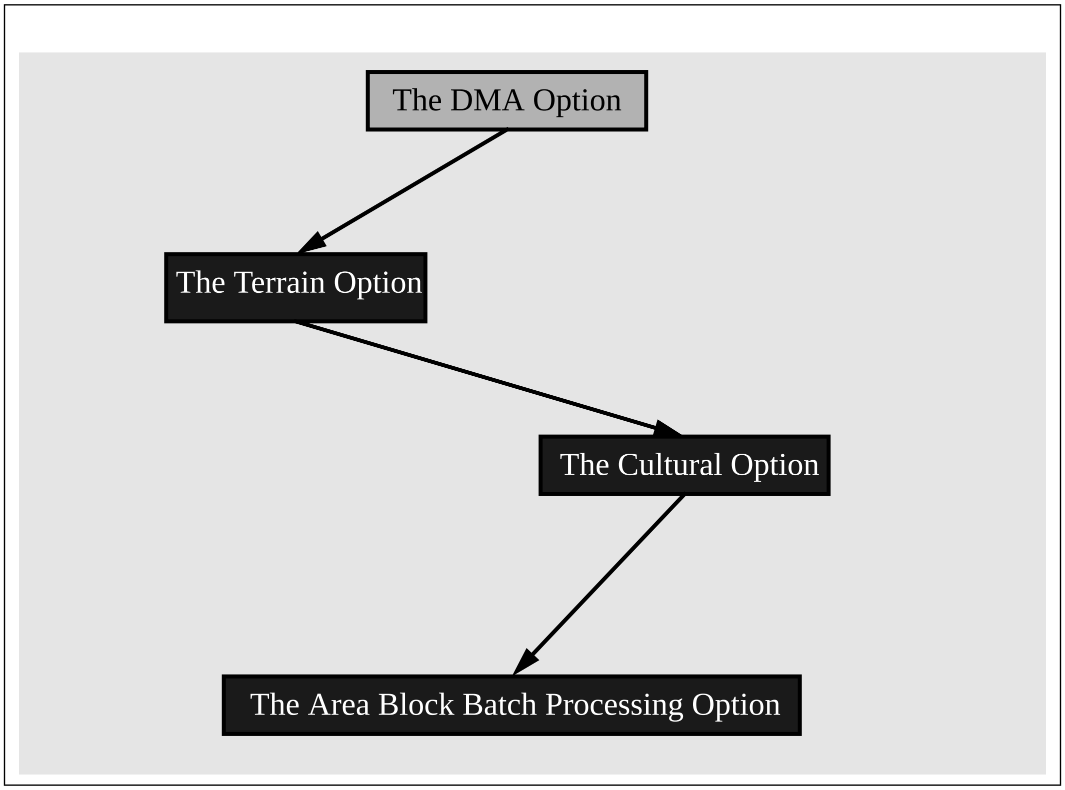


**Figure 27: The DMA Option Components**

## E. USING TERRAIN DATA WITH MULTIGEN

In Chapter VII, we provided a lengthy discussion of the basic makeup and characteristics of DTED data, as a result, we will not do so here. However, we will discuss how MultiGen is able to accept DTED raw data and by way of a conversion process make full use of the data in the creation of a three dimensional terrain database.

By this stage of our research, the decision had been made as to the selection of a particular geospecific area of interest. First, we sought to obtain terrain data from a number resources which covered our geospecific area of interest. We felt that since our principle goal was to pursue the highest level of TIR, then the best or highest level of terrain elevation data available that fulfill this requirement was necessary to create the desired topological features in our database.

Upon obtaining the raw data, we later discovered that MultiGen's Terrain Option does not work on raw DTED cells (See Chapter VII for review of DMA terminology). Instead, cells were read in and converted to MultiGen's internal format, referred to as *post file format.* By doing its conversion in this manner, MultiGen speeded up the overall processing method since one post file may contain data from many original cells, and because MultiGen preserves some extra information, such as the area's maximum and minimum elevation.

### 1. Terrain Conversion Process

The process of converting raw DTED terrain elevation data into polygons for use in MultiGen is a three step process (Figure 28). The first step, involves reading the data from the tape, disk or CD and converting it to a post file format. For a more detailed explanation, you are referred to *MultiGen's DMA Option Manual*.

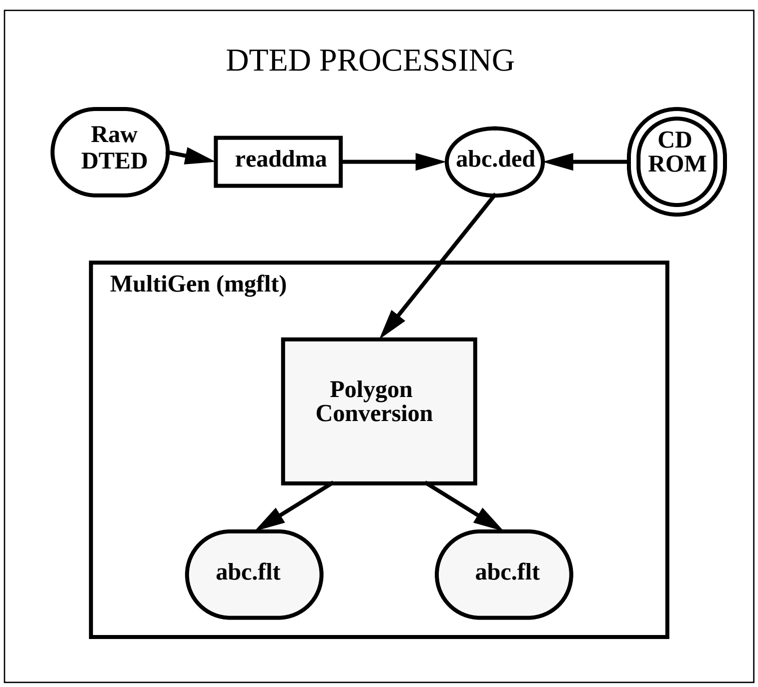


**Figure 28: MultiGen's DTED Processing Method**

After reading in the data and performing the conversion of the data from the disk into post file format, the next step involves reading the newly formatted data into the contour viewing window and selecting the areas of interest. Afterwards, adjust the parameters used for conversion to polygonal data.

Once the conversion parameters have been determined, a polygonal database is built by executing either of the Delaunay or Poly Mesh algorithms. Both algorithms produce databases which can be viewed and edited in MultiGen.

#### *a. The Poly Mesh Algorithm*

The Poly Mesh Algorithm creates rectangular terrain objects which contain one, two, or four polygons. The size of each object is determined by the value in the post spacing preference in the *polygon transformation* control box. A post spacing of sixteen, for example, means that the corners of each sixteen by sixteen array of post that will be utilized as vertices in the new database. These corners are tested to see if:

1. The four corner vertices are coplanar, Figure 29a.

2. The sixteen by sixteen gridded post block contains a deviant value greater than the Tolerance (ft.) preference in the terrain conversion controls. If it does, four polygons are created to represent the block, Figure 29c. If there is no deviant grid post, and the points are not coplanar, two triangular polygons are created as in Figure 29b.

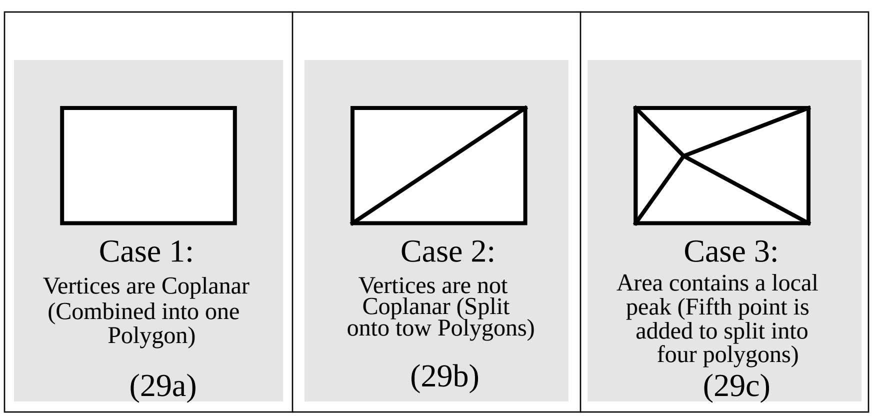


**Figure 29: Creating Polygons with Polygon Mesh Algorithm**

#### *b. The Delaunay Algorithm*

The Delaunay Algorithm breaks post data into triangles by searching for ridges, valleys, edges of flat areas, and areas of high curvature. The height of each sampled post is averaged with that of eight sampled posts surrounding it. If the average height of posts differs from the elevation in the center post by less than the Delaunay Tolerance, that posts is skipped in the triangulation.

The interval at which elevations are sampled is controlled by the Post Spacing preference in the *polygon conversion* control box. A value of sixteen, for example, cause the Delaunay Algorithm to process every sixteenth post, Figure 30.

### 2. The Culture Conversion Option

MultiGen's Culture Conversion Option allows for the placement of cultural features on to the previously converted DTED data. However, we were unable to utilize this particular feature, we've chosen to be very brief in our description of it.

Defense Mapping Agency Digital Feature Analysis Data (DMA DFAD) is often referred to as cultural data because it describes artificial objects such as roads and buildings, as well as, natural features such as forests and rivers. The primary purpose of this feature is to convert this data to polygons suitable for use on an image generator and to allow the display and edit of these polygons. The Culture Conversion Option can process levels I, I - C, II, and X DFAD files.

This particular option reads a translated version of a DFAD manuscript and produces a wireframe display of its contents. Each item drawn in wireframe is a construction object that can be manipulated by normal MultiGen tools and by the commands in the DFAD menu.

The option works by converting raw DFAD to an internal "dfd" format designed for efficient processing. Once a block of data has been converted, it is written to a new file with the same name appended by.dfd. (For more detailed information refer to *MultiGen's DMA Option Manual*.)

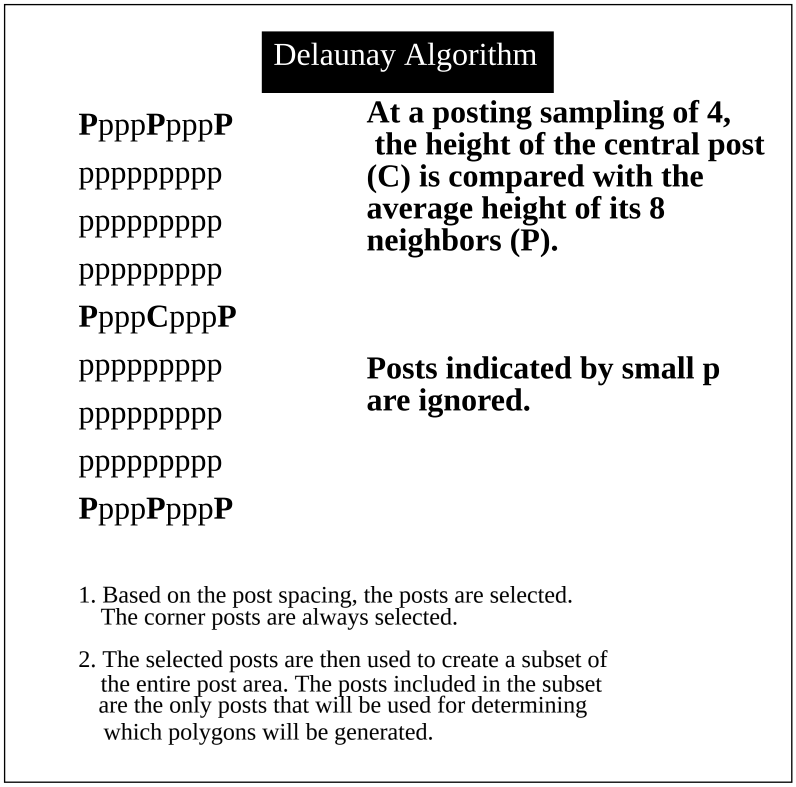


**Figure 30: Testing Points for Inclusion in the Triangulation**

### 3. The Area Block Batch Processing Option

This third and final component of the DMA option in MultiGen, is simply an extension of the Terrain and Culture Conversion options that lets you partition a terrain for automatic conversion into many separate databases. The database area can also be populated with models using the automatic DFAD feature extraction.

Batch processing has two advantages over manual database generation. First large geographical areas can be processed without the intervention of a modeler. Second, databases produced in one batch fit together smoothly at the boundaries, so an image generator can switch smoothly from one database to another (or the next).

## F. CREATING DATABASE MODELS

### 1. Master geographic database

As mentioned earlier, MultiGen was used to develop the master geographic (water and land) database. Rather than creating a new geographic database whose features would be subject to inaccuracies, an existing electronic topological database, based on satellite imagery, was obtained from the Department of Defense's Defense Mapping Agency (DMA). This data is known as Digital Terrain Elevation Data or DTED. MultiGen's DTED conversion utility described earlier enabled the conversion of the raw DTED data into MultiGen flight format for editing and later utilization by the IRIS Performer simulation utility. Without this utility, the individual polygons that comprise the terrain features would need to have been individually created. This process would have been time consuming and would not have taken advantage of existing data which has an accuracy of seventy-five meters.

To ensure that we attained the highest level of TIR possible, we contacted the City of San Francisco's Department of Transportation and obtained copies of several detailed drawings of the Golden Gate Bridge and surrounding structures. Although CAD data was available, we were not able to make use of it due to the absence of the DXF option in our modeling application package. As a result, our overall development time could have been reduced significantly if the DXF option had been available. Additionally, we purchased several text on the bridge so as to have an insight into the overall history of the bridge. This aided us tremendously in the development process of the database. We actually felt as if we were the original architects behind rebuilding the city after a major disaster had totally demolished it or we were the original settlers or developers who had come to build a brand new city from scratch.

Early on in this chapter, we discussed the two algorithms which allowed us to produce the database we are currently using in our research (refer to Using Terrain Data with MultiGen above). After completing our use of MultiGen's Area Block Batch

Processing Option to create the database, we proceeded to begin designing the models for inclusion into the database. However, before we take up the topic of modeling, we will examine the end product of the DTED terrain conversion process in Figures 31 through 33 below.

In Figure 31, an illustration of the landmass centered about the Golden Gate Bridge and the mouth of the bay is displayed. The black lines shown in the figure illustrate the polygons and vertices created when the raw DTED data was converted by MultiGen using the Poly Mesh Algorithm. The darker colored areas depict water both within and outside of the bay. While the lighter shaded areas indicate terrain (or landmass). The lighter the color, the higher the elevation in those particular areas.

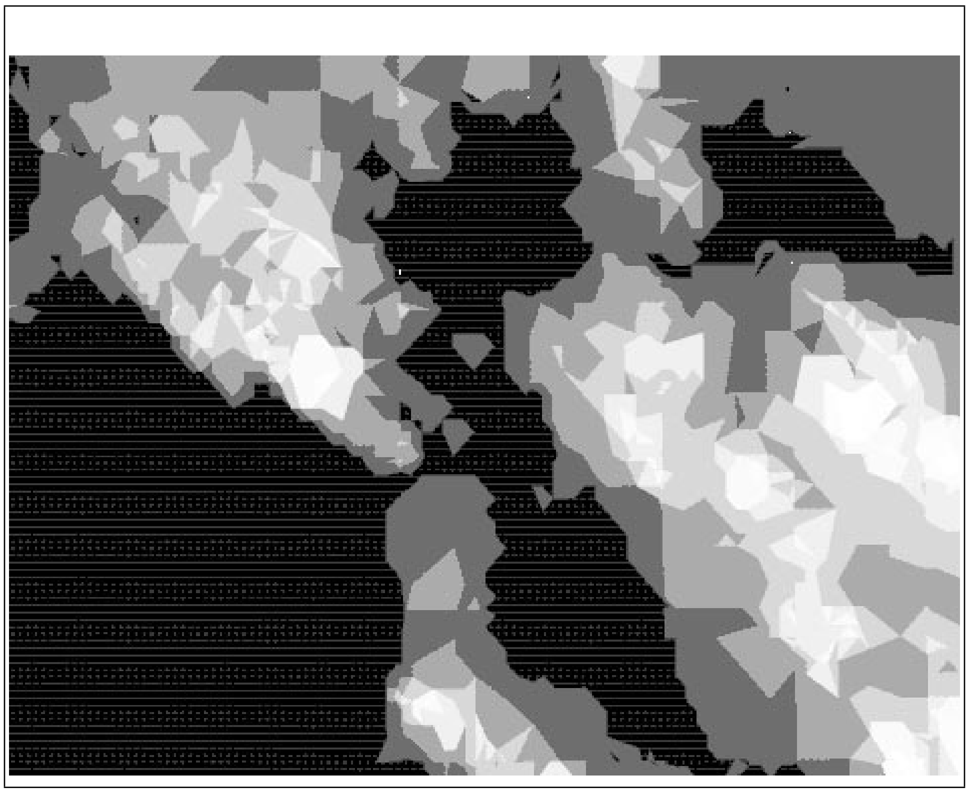

**Figure 31: Converted DTED Data for San Francisco Bay**

Shown in Figure 31 is converted DTED data with the vertices and edges of polygons. Each vertex indicates an elevation value of zero or positive floating point value and the darker colored areas symbolize water while the lighter tones indicate terrain. Mind you, both Figures 32 and 33 are large scale illustrations of the targeted area.

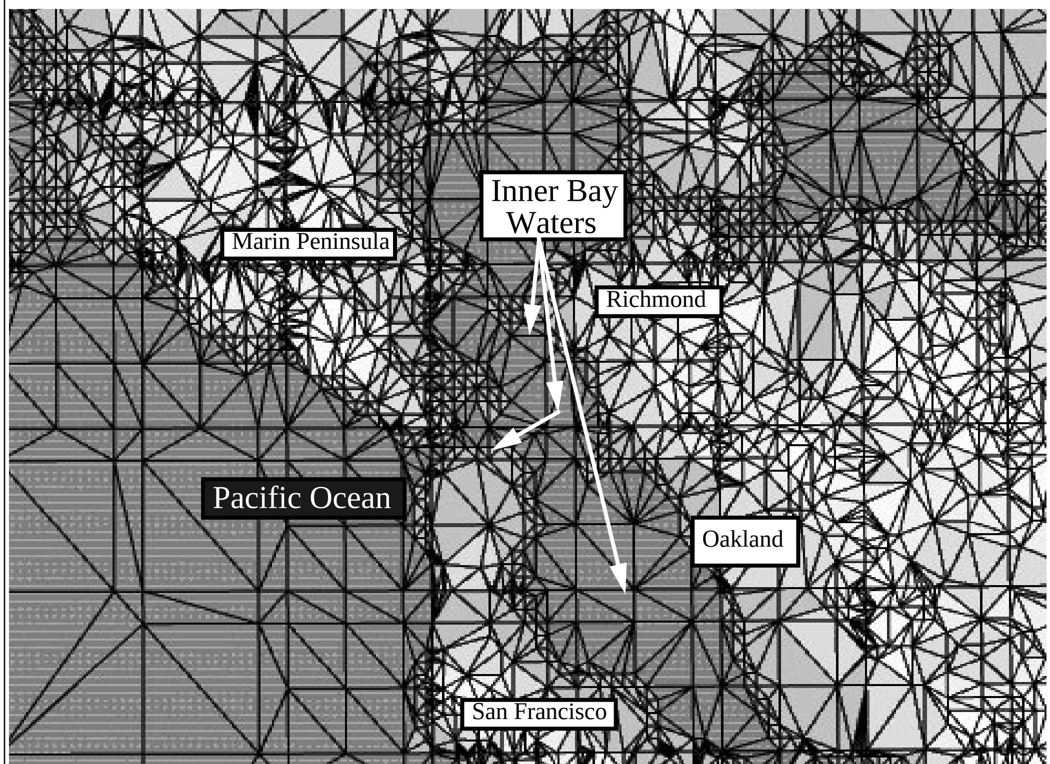


**Figure 32: Converted DTED Displaying Polygons**

Figure 32 is an illustration of one of the terrain segments described in Chapter VIII These sort of segments (or cells) were used to manage the design and development of required three dimensional models for the areas surrounding the low line coast within the bay. Such a small scale segment allowed us to focus in much more closely on the geospecific location to study the probable location of various cultural structures such as the Golden Gate Bridge. Given the topographical maps and architectural drawings obtain from the Golden Gate Bridge, Highway and Transportation District, we were able to place the previously constructed model into the database with far greater precision than what could have been done by any other means short of the use of actual DFAD data. The DFAD data would have allowed placement at an even greater precision. However, our current version of MultiGen was not equipped with the DFAD option.

One method of constructing a terrain database was to create a segment for an origin

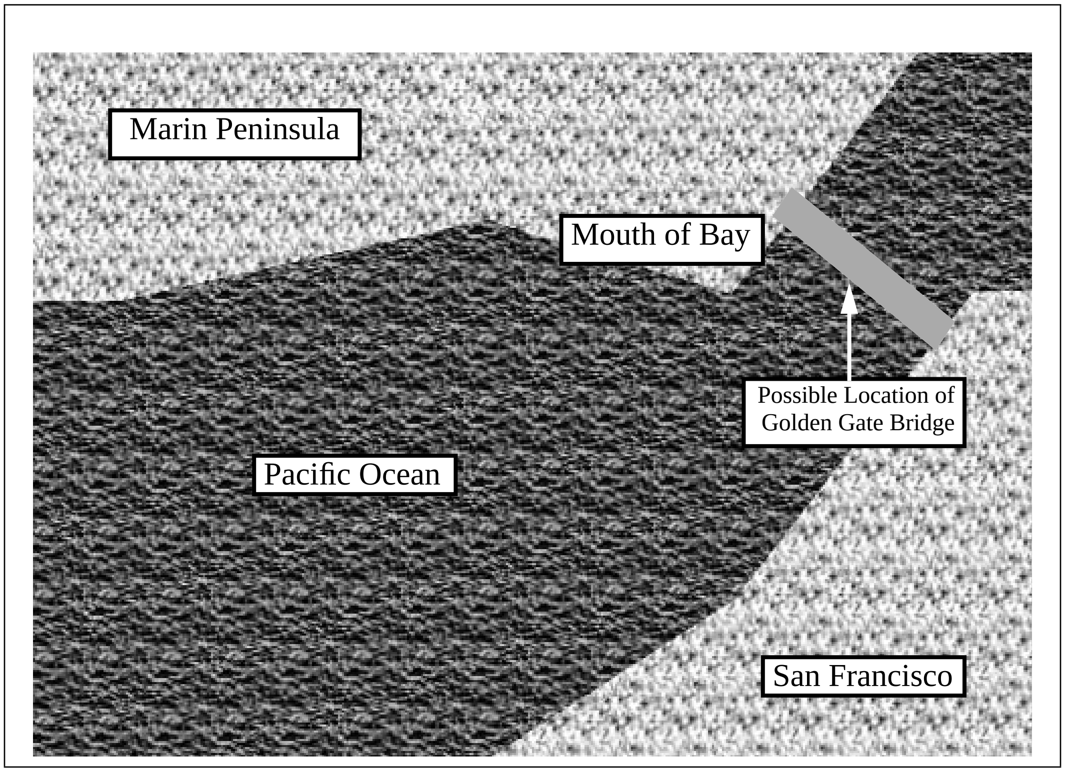


**Figure 33: Small-Scale Segment of Terrain**

and then to make all additional segments external references to that particular segment. This is done automatically for us with MultiGen's Area Block Batch Processing Option. What we gained from this feature was the ability to load the terrain database first and then load any required models as were needed according to the current view frustrum of the user. As the viewpoint changed, we could cull the unnecessary models, thus improving overall performance. With the exception of a few models, all were loaded from our *sfbaymodel.dat* file. In the case of each model, we created both a lighted and unlighted version. This further aided in our design process in that we now could set the time of day and cause a switching out of models between day and dusk hours. Below in Figure 34 is a view of the hierarchical structure depicting the externally referenced terrain segments.

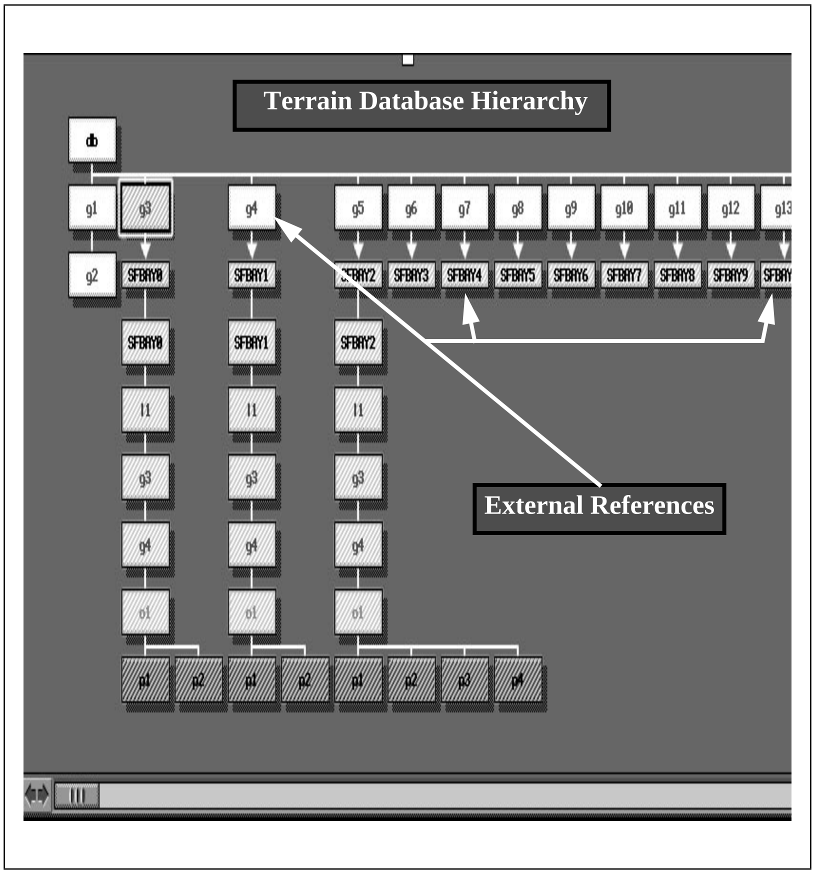


**Figure 34: Externally Referenced Terrain Segments**

### 2. Truth-in-Representation: What to Model in Your Database?

As in the case with any simulation database design, there will be a need to create a myriad of different models. These models may consist of an entire city block area, (e.g. the Fisherman's Wharf area, which consist of over two hundred individual buildings), to an area the size of Alcatraz Island, where there are less than two dozen individual building structures. Regardless of the number of models, once again, the decision must be made early on in the design and planning phase as to what level of detail (or truth-in-representation) the database is going to have. This will be the single most important factor when developing other important facets of the database.

In considering the types of models, entities, or objects that should go into the database, we began with a very basic list of all of the features that we felt a shiphandler or conning officer would observe if he/she were operating in the vicinity of the inner harbor. Additionally, it we were of the opinion that the database should include all of those objects one might encounter in the visual scene or numerous viewing frustrums experienced in our database. At a minimum we sought to create or model the following:

- Ownship's bow image.
- Traffic vessels with their own navigation lights of green, red, white and amber coloring.
- Sky, without clouds or sun.
- Water without waves (texture).
- Land mass with shoreline contours.
- Aids to navigation. To include floating buoys, light towers, lighthouses, and day marks along with the appropriate lights utilizing red, green, and amber.
- Piers (One pier visible on the docking side in the scene including light poles, pilings buildings or other structures as aids to navigation.
- Cultural lighting depicting lights on culture structures. This would require the development of both lighted and unlighted models for most entities or objects in the database.
- Atmospheric effects - to include dusk and fog.

Once again, since our objective was to attain the highest level of TIR, it was imperative that we establish a well thought-out modeling management plan that would ensure both rapid and accurate modeling construction. One additional characteristic should be mentioned here with respect to the database - that being the size of our gaming area. As in the case with the full-scale mock-up, the gaming area for the data base was twnety nautical miles by twenty nautical miles. However, due to the hardware constraints of our design, we were unable to achieve the minimum hydrodynamic modeling accuracy of 80 percent.

Below is a list of those features found in the full-scale simulators. If not for the time constraints and lack of financial funding, there is little doubt that our final database could have included many of these very same features.

- Bottom Depth
- Sidewall (channel width, bank, slope, sidewall height)
- Piers (open and closed pilings)
- Traffic ships (initial conditions and preprogrammed maneuvers).
- Traffic ships include large merchant, small merchant, sail boat, tugs with tow and naval ships.
- Fleet ships anchored/moored
- Current patterns (flood and ebb for each data base) (streamline flow in rivers and jetty entrances and unidirectional flow or multidirectional flow in open sea or bays. Current patterns shall be selectable in direction and magnitude.
- Bottom type (mud, sand, rock)

### 3. Placement of Models into the Terrain Database

Once models were completed the tricky part became their near accurate placement into the terrain database. This was not at all an easy task simply because we were dealing with elevated terrain. Much of the previous research conducted in the area of simulation database design (or virtual environment technology) [AIRE90] [GRIN93] [JEPS93] [YOUN93], was modeled on a flat or horizontal surface. This greatly enhanced the developers ability to accurate place constructed models within the world. This dilemma significantly hindered the development progress of our database as a whole. In order to minimize the impact, we discovered in Iris Performer's *libpr* library the *pfPreRotMStack()* function which allowed pre-multiplication of the top of the transformation matrix stack. This function allowed us to transform our models in degrees about the axis which was defined by x, y, and z. Thus our remedy became twofold.

First we began by taking each model individually and placing in to a models data file (*sfbaymodels.dat*). Here we placed all of our stationary models or landmarks for the database and assigned each an integer value which served as a tag denoting which type of model it was. An "O" signified that the model was an *offshore object* which further meant that it was an object that was subject to collision by ships. While on the otherhand an "L" was assigned to those models placed on land and signified that the model was a land object which the ships could not collide with.

The next portion of the model assignment field was the actual X, Y, and Z coordinates for the model. The proceeding number in the assignment field was the axis of rotation. This procedure was used to orient the model. An example is provided in Figure 35.

Here we see in Lines 1 and 2, a listing of two flight models with the filename of Blimp.flt. The model in line 1 is an unlighted version of the blimp, while the model in line 2 is the lighted version. As the reader may recall, associated with our time of day function, these models are directly associated with a switch node that allows the swapping out of either of the two model types based on the time of day (which is a 0.60 time factor).

The two digits immediately following the model's filename pertain to the object's collision masks that are set as they are loaded. The first digit represents where in the scene hierarchy the model is to be placed (refer to Chapter IV). Objects with a first digit of "0" are land objects and are added as children of the landObject node of the scene to eliminate intersection testing since the ship does not run into things over land. The second digit following a "0" is merely a placeholder to maintain consistency in the program loop that loads the models and bears no significance. Objects with a first digit of "1" are objects located in the water and are added as children of the offshoreObject node in the scene hierarchy. For these objects, the second digit represents the specific type of object they are to allow the program to determine how the ship should react should an intersection test with the object return a positive result. For example, a collision with a bridge (second digit "2") should cause the ship to either come to a stop during a head-on collision or fend off to the side if the side of the ship hits. A ship hitting a buoy (second digit "3") would not behave the same way and therefore would proceed over the buoy. For example, in the case of the Alcatraz.flt series models, the "1" indicates that the island is an offshore object eligible for intersection testing while the second digit tells the ship to halt when a positive intersection is returned. What this method amounted to was to place the models by manipulating the models yaw, pitch, and roll components about the centroid of the model.

```
 (Line 1) M 3 17 blimp.flt  0 1
 (Line 2) M 17 3 blimp.flt  0 1
 (Line 3) C 44627.2 89712.2 250.0 0.0 0.0 0.0 250.0

 (Line 4) M 5 19 Alcatraz.flt  1 2
 (Line 5) M 19 5 Alcatraz_lites.flt  1 2
 (Line 6) C 49395.790 91831.453 0.5 0.0 0.0 0.0 0.5

 (Line 7) M 6 20 wharf.flt  1 2
 (Line 8) M 20 6 wharflites.fl 1 2

 (Line 9) C 50283.2 90507.8 8.0 -90.0 0.0 0.0 8.0

M 1 15 GG.flt  1 2
M 15 1 GGlites.flt 1 2
C 44627.2 89712.2 1.0 20.0 0.0 0.0 1.0
#C 44527.2 89712.2 1.0 20.0 0.0 0.0 1.0
M 7 21 LightHouse1.flt 0 1
M 21 7 LightHouse1.flt 0 1
C 50000.0 91831.453 5.0 0.0 0.0 0.0 5.0
M 8 22 SF_Buoy1.flt 1 3
M 22 8 SF_Buoy1.flt 1 3
C 40046.8 88563.1 7.0  0.0 0.0 0.0 7.0
```

**Figure 35: Sample Static Model Entries in Static Model File**

### 4. Model Statistics

There were a number of models created to attain the highest level of TIR for the database. Appendix D contains tables showing the specifications for each of the models created. These statistics aided in development of the database overall by helping us to maintain our performance goal of fifteen frames per second (plus or minus three frames). Initially as we added individual models, we tested our system to evaluate system performance while traversing the database.

The statistical data was made possible through the use MultiGen. The following is a brief summary of the information provided regarding a selected database:

- Number of Polygons (Faces) - The actual number of polygons found in the model. As was mentioned earlier, a polygon is a collection of ordered, coplanar vertices describing a surface.

- Number of Vertices - The number of points of intersection within the model.

- Number of Levels of Detail - This number indicates the number of levels of detail created for this particular model. Levels of detail are models which are only displayed within a predetermined range from the eyepoint. This allows the image generator to make objects appear increasingly complex as the eyepoint approaches by replacing a low resolution model stored under one LOD with a higher resolution model stored under another LOD.

- Number of Groups - As mentioned earlier, groups are the highest level in the hierarchy that a modeler can create. These groups can contain other groups, objects, and levels of detail and are quite useful for organizing parts of the database that will be manipulated together.

- Number of Objects - Objects are the collection of polygons. As a good modeling practice, we discovered that by keeping each models objects as simple as possible and by making use of convex polygons, enhanced overall performance by avoiding the limitations of the drawing hardware. Once again, such measures, although small by comparison to other learned techniques, proved to provide overall structure and integrity for those models in the database.

- Models Coordinates: - The coordiates for each of the models aid in facilitating correct placement of the models into to the larger terrain database. Most of the models created, were externally referenced to reduce the overall size of the an be exter

- Texture Statistics - This data consist of the actual numbers of specific types of the various textures applied to each model. Additionally, MultiGen keeps track of the size of those textures being used and provides a final total of the required memory needed to rendered them during actual execution of the system. This sort of information becomes increasingly critical when designing a single server system which might possess limited texture memory.

MultiGen allowed us to display and interactively manipulate the three dimensional objects or models as they were being created. Although objects had to be created on a polygon by polygon basis, MultiGen provided a reference plane to aid in determining the locations of the vertices needed to construct the graphics primitives (i.e. lines and points). Furthermore, other graphics primitives (i.e. circles, arcs, rectangles and ellipses) can also be created. Other functions such as automatic normal calculation (for lighting), mip mapping and the ability to move entire sets of polygons or objects within the database provided a high degree of flexibility during the entire modeling effort.

Moreover, other rendering attributes (i.e. scaling, texturing and lighting were applied directly to each object utilizing easy-to-use functions provided by the MultiGen. For large area databases such as ours, the flying function inherent with MultiGen, provided a readily available means to move within the database. With the mouse as our chosen pointing device, we were also able to position the individual vertices during polygon creation. For the shiphandling simulator resulting from this research, the MultiGen application tool was used to create the numerous three-dimensional objects required (i.e. bridges and buildings). Once the database was finally created, it is loaded into a simulation application such as IRIS Performer in support of an actual three dimensional real-time simulation system.

## G. SUMMARY

The creation of a large geotypical terrain virtual world database, requires significant planning and careful management of both human and material resources. In the development of such a database, the proper use and management proved time and time again that careful and continuos monitoring is the only way that successful software development techniques can be effectively applied.

Additionally, what this research has revealed is that there is and remains very limited research data available regarding the design and development of large scale terrain databases. Such shortfalls in this area reduces the availability of sorely need specialist in the area of creating terrain databases for a number of global applications.

It is without question, that the amount of time required to model such databases can prove to be the most taxing of all when developing large scale terrain databases. Thus, careful consideration, keen planning, and early and meticulous design procedures must be considered before taking on such a project of this magnitude.

# VII. NETWORK INTEGRATION

## A. NPSNET DESCRIPTION

The Naval Postgraduate School Networked Vehicle Simulator IV(NPSNET -IV) is a three-dimensional, real-time combat simulator developed by the Naval Postgraduate School Computer Science Visualization and Simulation Laboratory to provide low-cost battlefield simulation training [ZYDA93]. Hosted on Silicon Graphics Incorporated (SGI) graphics workstations, NPSNET is designed to interact with other stations or nodes on a network using Simulation Network (SIMNET) and Distributed Interactive Simulation (DIS) network protocols. For example, a person driving a tank on one node will see the helicopter being flown by another person on another node. Furthermore, NPSNET has provided a research tool for students to apply their warfightiing knowledge by integrating the characteristics of their particular warfare area (e.g aviation, infantry, armor...etc.) into a virtual battlefield simulation.

## B. PURPOSE

The defense drawdown has created the necessity for the armed services to interact more with one another. At the same time, the drawdown has made scarce the availability of funds necessary to support live joint service training exercises. With this in mind, a need arises for quality training to be provided by simulation within virtual worlds.

A ship's involvement in joint exercise training may involve participation in amphibious landing exercises or providing naval gunfire support (NGFS) to personnel on the beach. In these scenarios, ships will be operating in close proximity to one another where the possibility of collisions at sea exist. Moreover, NGFS may require a ship to operate close to shore where a possibility exist for it to run aground. It is for these types of scenarios that shiphandling training must be incorporated into joint battlefield simulation.

## C. NPSNET CLASS HIERARCHY

NPSNET implements an object oriented design written in C++. Using the IRIS Performer application programming interface (API), rendering speeds on multiprocessing systems are optimized. With an object oriented design, common vehicle characteristics can reside in a base class (VEHICLE), with the vehicle-specific characteristics residing in inherited classes (Figure 36). For example, the base vehicle class can perform all general functions such as initializing velocities and postures, processing and sending network information and dead reckoning all the vehicles in the scene whereas the inherited classes performs functions tailored to the characteristics of the vehicles they represent such as maneuvering functions used by ships.

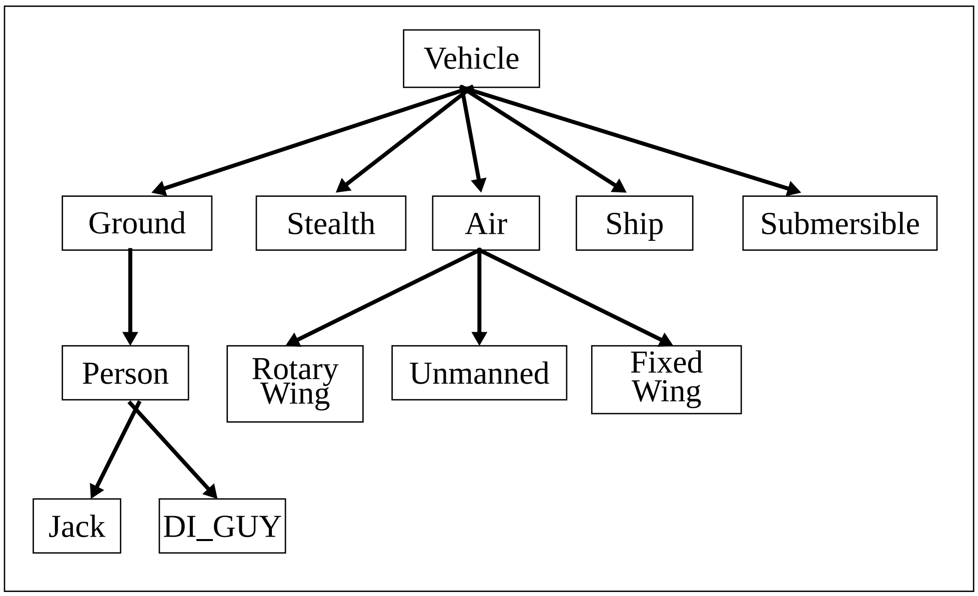


**Figure 36: NPSNET Vehicle Hierarchy**

For functions sharing a common name, but whose implementation is different (such as a function to move that particular type of vehicle), a virtual function of that name is declared in the base class with the more platform specific (also of the same name) declared in the inherited class.

## D. ADDING A SHIP TO THE NPSNET CLASS HIERARCHY

The structure of the NPSNET vehicle hierarchy made adding a ship to the hierarchy fairly simple. Furthermore, the NPSNET data structures were utilized to take advantage of existing NPSNET functions, enabling a ship to, someday, support NPSNET battlefield simulations. Moreover, the flow of the deployable shiphandling simulator program mimics that of NPSNET in that all ships other than the driven ship are dead reckoned by each individual node on the network until information is received from the network. To take advantage of the existing NPSNET functionality, the ship (SHIP_VEH) class was expanded to support the unique characteristics of a ship. Most of the common functionality defined in the base vehicle class needed no modification while some needed changing (or redeclared as virtual functions) to support unique ship and simulator support characteristics. Weapons capability was not incorporated since the sole purpose of the shiphandling simulator was to train bridge watchstanders to safely maneuver a ship. With regards to adding a playback capability, additional functionality was added to the vehicles class to enable each ship involved in playback to “retrace its steps”.

### 1. create_entity(int, ForceID)

The create_entity function is used to add vehicle geometry to the scene hierarchy for both the driven vehicle and all other vehicles received from the network, figure 37. For each vehicle being created, a dynamic coordinate system (DCS) is created to “hold” that vehicle’s geometry as it moves through the scene. The geometry that gets assigned the vehicle is determined by the integer argument passed into the function. This integer acts as an index into an array of vehicle types which holds data on each vehicle type. Included in this data is a switch node that switches between the vehicle’s different models (alive/dead or unlighted/lighted). The selected switch in the vehicle type array is then copied (or cloned) becoming the new vehicle’s switch node. The cloned copy is then added as a child to the new vehicle’s DCS. An intersection (collision) mask used for intersection testing is then assigned to the new vehicle. The DCS is then added to the scene hierarchy. Most of the functionality in the original NPSNET IV version of this function was used except for the assignment of collision masks. For the vehicles being driven in an NPSNET simulation, the driven vehicle is normally not displayed when the user is “in the driver’s seat”. For ships, display of the driven vehicle’s or driven ship’s geometry (particularly a view of the foredeck) is required. This presented a problem with the NPSNET implementation because during intersection testing, a line segment is extended straight out from the center of the DCS in the direction of motion of the vehicle to detect object geometry that might be in its path. With the ship’s foredeck displayed, this segment intersected the driven ship’s own geometry resulting in the execution of functions related to collisions with other ships (i.e. the ship coming to a halt). To eliminate this problem, the driven ship is assigned an intersection mask (0x00) that prevents it from “colliding with itself”.

### 2. check_collide(pfVec3 &, pfVec3 &, pfVec3 &, float & float &)

The check_collide function is used by the driven vehicle to check for collisions with the terrain, and predesignated objects within the viewing frustrum. As mentioned above, collision detection is performed by first extending line segments (pfSegs) outward from the driven vehicle and then determining whether they intersect the geometry of objects we wish to check against (based on the active collision mask set). The length and direction of these segs depend on the area, with respect to the driven vehicle. For example, a missile targeting lock is modeled by extending segs a considerable distance in front of the vehicle. When the segs intersect an object, the scene (or a particular subtree in the scene) is traversed checking each node in the hierarchy by bitwise ANDing the object’s collision mask with that of the active collision mask. If a zero is returned from the bitwise AND operation, then the remaining nodes (or children) in that particular subtree are ignored and the traversal continues in other parts of the scene. If a result other than zero is returned, a collision has occurred and a weapons lock-on is established.

The ship’s implementation of this function only performs intersection testing against objects normally in the water such as bridges, wharfs and other ships (refer to

Chapter IV for the scene hierarchy). Furthermore, the segs used during intersection testing are arranged on the ship to allow specific reactions to occur based on whichever segment detects an intersection (Figure 38). Intersections detected by segments along the ship's centerline (segs 0, 1) will cause the ship to stop as if the object it collides with is blocking its forward motion (as it would in the real world) whereas intersections detected by segments along the beam of the ship (segs 2, 3) will cause the ship to repel in the opposite direction to the side it hits. If a ship collides with another ship, the ship comes to a complete halt with all propulsion input (shaft speeds) initialized to zero.

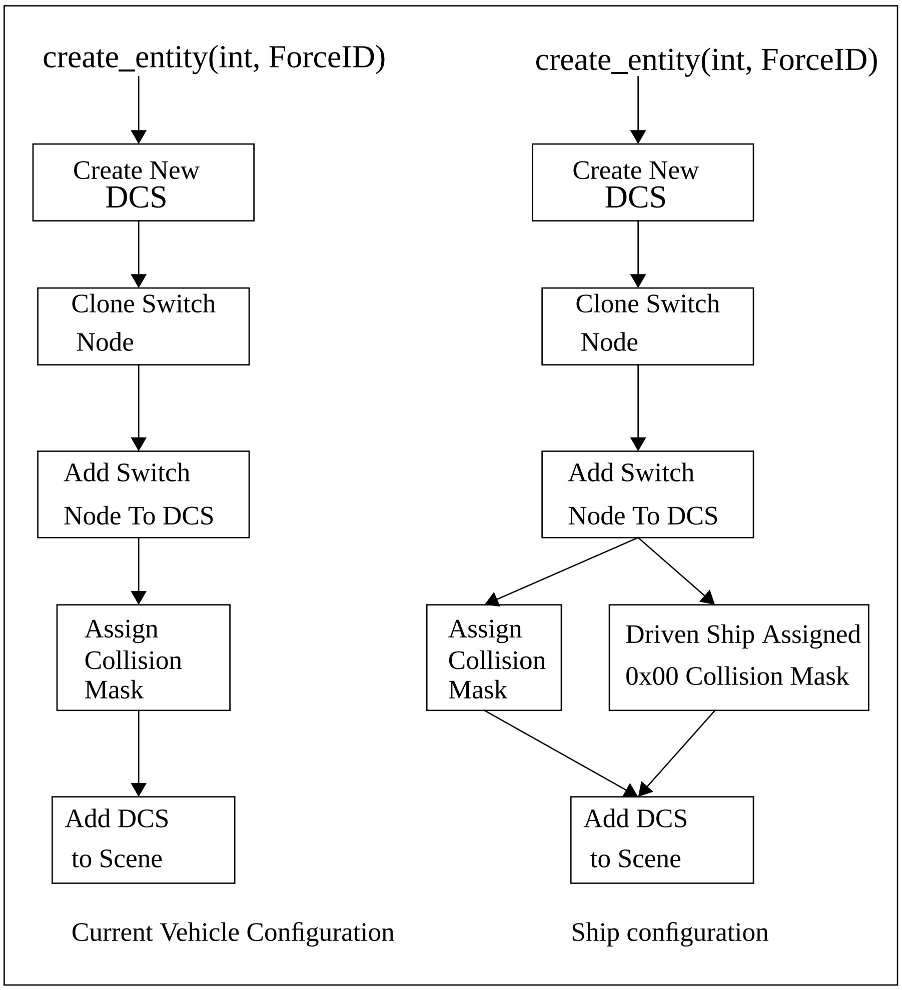


**Figure 37: Flow of create_entity Function**

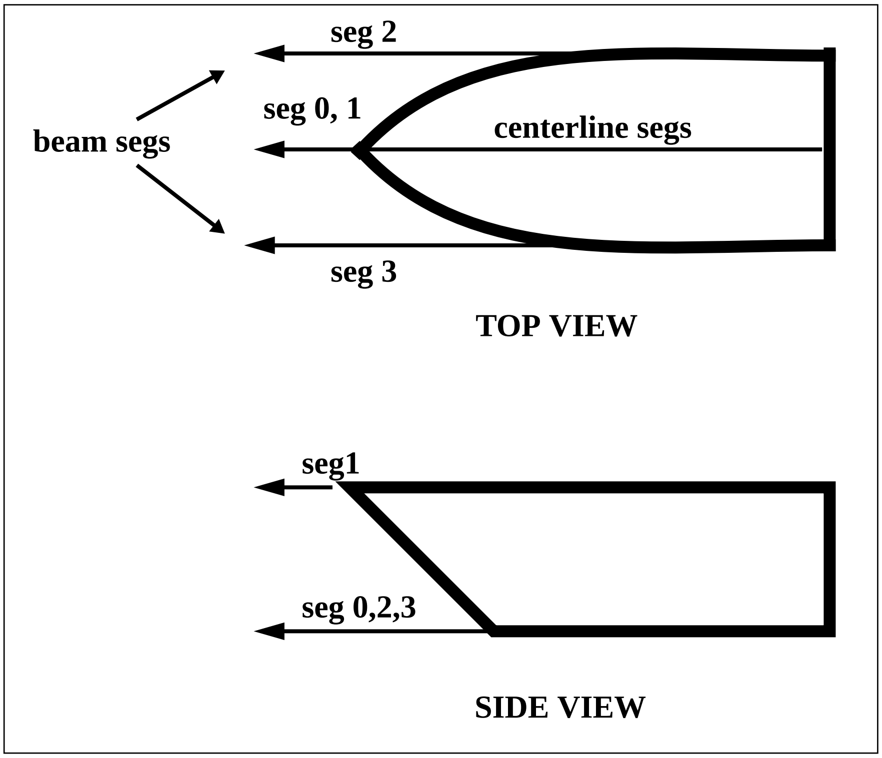


**Figure 38: Line Segments Used for Intersection Testing**

### 3. move(PASS_DATA *, CONTROL_DATA &)

Prior to every frame, the driven ship updates its position based on the controllable forces generated by its rudder and shafts. It is within this function where the hydrodynamics equations are located (refer to Chapter V). PASS_DATA and CONTOL_DATA consist of control panel inputs to adjust the speed of the shafts, rudder angle inputs and time increments required in equations of motion calculation.

### 4. moveDR(float, float)

After updating the driven ship's state in the move() function, the remaining vehicle positions are dead reckoned along their most current heading change from either their previous dead reckoned positions or an updated one received from the network. The driven ship also dead reckons its position to determine whether there is a difference between where it holds itself in the world and where all other nodes in the network do. If the dead reckoned position falls outside of dead reckoning parameters (3 meters difference in distance, 3 degrees difference in heading), the sendentitystate function is called, resulting in the driven ship sending an entitystate PDU over the network. Other criteria for sending the PDU includes a 5 second gap in PDU transmit times and changes in speed. For ships, an entitystate PDU is also sent for non-zero rudder angles.

**5. sendentitystate()**

As mentioned above, this function is executed from the moveDR function whenever the driven ship determines the need to transmit an entitystate PDU. Upon execution, this function creates a new entitystate PDU and "fills in" the data fields of the PDU with identity, location and maneuvering parameters for other nodes on the network to identify, create and update a ship's position within their own scene. Transmission of the entitystate PDU is accomplished using NPSNET's disnet_manager class functions.

In addition to performing network send functions, the sendentitystate function also records the entitystate PDU information, along with other state information such as time of transmit, rudder angle and shaft speeds into a script file to be used by the playback mode.

**6. entitystateupdate(EntityStatePDU *)**

Entitystate PDU's received from the network on a specific ship are sent to this function to parse the needed information fields from the PDU to update that ship's posture, velocity and for battlefield simulations, an appearance field to switch between a vehicle's living and dead model geometry. For PDU's received on ships, the appearance field is not used to switch the ship's geometry in order to give conning officers positive control over their individual scenarios. Therefore, the decision to perform a day or night scenario where all ships should have the same running lights status is left up to the conning officer.

Prior to function termination, the entitystateupdate function records the information parsed from the entitystate PDU into the script file that is used in the playback mode.

Additionally, the received ship's vehicle list number and the time the PDU was processed is also recorded.

### 7. playBackUpdate(pfCoord, pfVec3)

During playback, all ships return to their starting positions and retrace the paths that they travelled during the real-time simulation. At the commencement of playback, all the legs or turnpoints are read from a file, stored into each ship's playback array and executed when the playback clock's time approaches a ship's time to execute a turn. The playBackUpdate function processes these turnpoints similar to the way that the entitystateupdate function updates a ship's position from the network. When the playback clock's value exceeds that of the turnpoints, the playBackUpdate function is called with the ship's updated posture (pfCoord) and its velocity vector (pfVec3) obtained from its playback array. Between turnpoints, the ship's position is dead reckoned based on the time and the velocity vector passed to this function.

### 8. playBackDR(float)

During playback, the playBackDR function updates ships' positions between turnpoints. Using the latest velocity vector passed to the playBackUpdate function and a time step, ships are dead reckoned along their current leg in the direction of their latest heading (which was the heading of that particular leg during the real-time simulation). This function is similar to the moveDR function used during the real-time simulation with the exception that with the playBackDR function, there is no evaluation whether to send an entitystate PDU and therefore, no call to sendentitystate which performs this function.

## E. SUMMARY

Incorporating the ship used in the deployable shiphandling simulator into NPSNET has been made possible through the use of NPSNET data structures and functionality during its development. Most functions within the NPSNET base vehicles (VEHICLE) class could be used without modification while some needed to be changed to support ship and simulator characteristics. Using NPSNET functions for transmitting and receiving PDU’s helped us meet DIS standards in the transmitting and receiving of entitystate PDU’s. Furthermore, with DIS standards met, the capability exists to include ships in battlefield (most likely amphibious landing type) simulation exercises.

# VIII. DEVELOPMENT OF TERRAIN DATABASE

## A. BACKGROUND

As stated in earlier chapters, the experience, knowledge, and insight gained from this research has been immeasurable. There have been a number of important pieces of research data reviewed throughout the entire research effort. Many issues or questions arose regarding how best to commence the design, development, and finally the actual implementation of our simulation database, moreover, we were quite unsure of the best means for designing, developing, and finally implementing a terrain database for almost any application? We can only add that through the reading of numerous research papers, we were somewhat surprised to find that there was very little if any information available regarding the actual processes for designing simulation databases.

Our objective at this point became threefold. First of all, we sought to identify those methods common to the actual design process. These were very common among researchers and institutions conducting research in the development of simulation databases or virtual environment technology. Secondly, we sough to identify specific techniques which made for increased optimization in the development process after a sound design plan had been formalized to serve as a guiding precept for the final database system. Finally, we wanted the results of the first two objectives to be assembled into a final research paper subsequent to this thesis work which would offer a comprehensive "how-to-guide" for designing, developing, and implementing a simulation database. (Understanding well in advance, that there would be others who may wish to perhaps challenge our precepts or ideas.) We hoped that the results would provide, much needed coverage of key design concepts in future research efforts to follow, thus, increasing the sharing of ideas and processes which we feel can only serve to make things better, more efficient, and most importantly -- cost effective.

## B. INTENDED APPLICATION OF THE TERRAIN DATABASE

For a any visual simulation to be considered a viable training vehicle, one must first understand human physiology as it controls and defines observer perceptions [JONE94]. Today's visual systems must be able to meet certain minimal requirements of design which allow for the highest level of realism and provide for the utmost degree of interactivity possible given the hardware and software limits of the tools in use.

For our application, which is a shipboard training simulator, we must have a realistic-looking three dimensional virtual world environment to operate in. Thus, by identifying what our intended purpose was for the simulation system, we were able to first gradually progress one step further and identify several additional key factors which we considered as sub-objectives or additional factors for consideration which are encompassed by this primary of goals -- deciding what the intended application would be for our simulation system.

## C. DESIGN CONSIDERATIONS

Over recent years as the cost of simulation systems have declined, the application for such systems has grown at an alarming pace. Current applications consist of teaching people how to drive an automobile or truck for the first time, to piloting aircraft, to operate cargo and construction cranes, to serve as railroad engineers, and to perform other tasks which require skills development that may be considered important especially in circumstances where the unavoidable mistake may prove fatal. [JONE94]

As mentioned earlier, our intended application or purpose was to develop a low cost, portable, shipboard training simulator. In doing so, our system must not only provide for watchstander training in the area of the nautical rules of the road, but equally important, be oriented toward providing training in the area of "situational awareness" with emphasis in manuevering in restricted waterways.

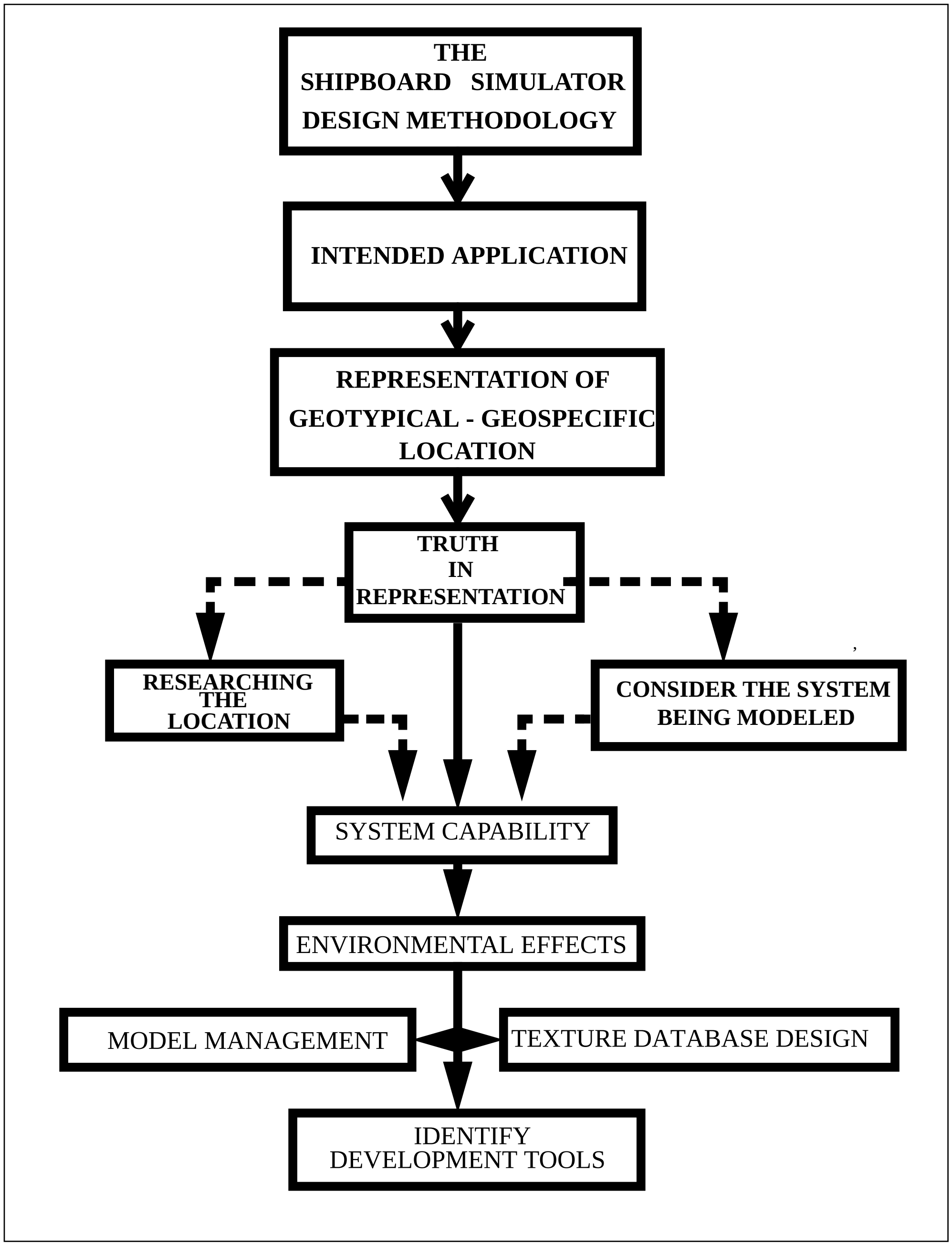


**Figure 39 : Factors for Consideration in Simulation Database Design**

When considering what factors might play a role in the overall scheme of such a training effort, we surmised the following issues had to be addressed. Figure 39, illustrates each of these key factors as part of a simulation database design model for use in any simulation development effort.

- **Intended Purpose.** Training, Mission Rehearsal, Prototyping
- **Representation of Geotypical Location.** This allows for a number of different scenarios. The current full-scale training simulators provide for a number of different terrain database locations (e.g. Norfolk, VA, Charleston, SC, San Diego, CA, etc.).
- **Truth in Representation.** We started by looking at the database from a macro-representation standpoint and then focused our attention on the micro-representation aspects of the database. The level of detail required for a specific location (geospecific) may required much research into the detailed features of the location (e.g. buildings, buoys (to include both type, numbers, and unique features associated with their location in a particular waterway). Since we were going to train for mooring to and getting underway from a pier, the degee of detail or truth in representation had to be considered for the design of those piers immeidately and within the surrounding cultural features.
- **Researching the Location.** This step became a logical one in the design process. Since, we were going to model San Francisco Bay for the purpose of conducting restricted waterway transit training, it became imperative to obtain as much information as necessary regarding the features and characteristics of the immediate vicinity where we intend to dock/moor our vessel. In the case of our research, we actually traveled to San Francisco to take pictures, and gather data which gave us a real feel for the flavor and fidelity required in our design with the principal objective being to provide the target user that sense of realism alluded to by Michael Jones [JONE94]. This became a forerunner to the next step in the design process.
- **Consider the System Being Modeled.** Early into our research effort, we made our focus in the area of training for transiting restricted waters. In doing so, such consideration centered on what key characteristics might go toward providing visual cues to the user that he/she is actually transiting such waterways (i.e. buoys, lighthouses, other smallcraft normally found within the inner harbor, background lighting often found during night time transit, prescribed day and night makers (e.g. dayshapes, and in the case of darkness -- prescribed running lights). This includes what level of population will be required to enhance system realism?
- **System Capability.** Later on in the design phase, a key question which became paramount was could we design our system such that it would be able to provide practice or prerehearsal training on a specific geotypical location (e.g. entering San Diego harbor, San Francisco Bay, etc.)?
- **Environmental Effects**. Although not something one would experience while traversing through a building or structure (e.g. a home, office, or urban area), but in the case of our system, the intend user is always faced with the likelihood of reduced visibility or inclement weather (e.g. fog, high winds, rough seas, etc.). This was a key consideration when trying to reproduce the most realistic system possible.

- **Model Management.** Obviously as the decision is made as to what the intended purpose of the database system was, we now concentrated on such issues as the types of structures which must be created to enhance our intend purpose for the application. Diagonally, we focused at a macro level on the numbers of models needed to achieve our goal of truth in representation. Since modeling proved to be a critical part of the development process, the time spent had to be tightly managed to prevent the construction process from becoming a tremendous time sump, thus, loosing precious manhours toward overall system development and implementation.
- **Texture Database Design.** The overall development of the system can be enhanced tremendously by this single phase of the design process. In fact, in his paper, [JONE94], Jones states that “Texture processing is arguably the single most important incremental capability of real-time image generation systems.” He felt that the presence and sophistication of texture processing continues to define the “major” and “minor” leagues of visual simulation technology. We’ll cover this all important topic later in the paper.
- **Identify Development Tools.** In today’s world of virtual environment technology, there are an infinite number of applications used in the development of some of the most highly sophisticated and elobarate real-time systems. Early on in the design phase, those tools which best fit the needs of our system development and greatly aided in the enhancement of efficient virtual world development were identified. There were a number of applications initially considered for use, however, we selected those which best afforded rapid development of three dimensional models to use.

These and many more factors/issues were critical in the design of our system. However, there were a number equally important issues what were not mentioned here. The following are but a few of these: hardware/platform selection, network environment, modeling and editing tool selection, optimization of performance, scene management, and importance of low-latency in image generation. Throughout the remainder of this chapter, we will make mention of key facets in each of the areas illustrated in our simulation design diagram.

### 1. Intended Purpose

The purpose of the system was not only to provide a viable training vehicle and alternative means to facilitate the training of today's young surface warfare officers, but also to provide familiarity in the areas of basic shiphandling, coupled with the development in the user, an appreciation for the nautical rules of the road, as well as, enhancement of the user's situational awareness skills. In order for the system or any simulation database to be effective as a training tool, it must possess certain characteristics.

With respect to area familiarity, the necessary "visual clues" such as land masses, cultural features, and landmarks must be present in the virtual world, in order to allow for effective navigation of the virtual ship/vessel. Furthermore, hazards to navigation must also be accurately represented to further add a sense of realism to the scenario and which will further hone the watchstander's skills in dealing with the dangers that are ever present in both the open ocean, near-land, and restricted waterway environments. Such realization further aids in the training of the shiphandler by enabling him/her to practice learned methods and procedures for preventing the virtual ship from running aground or colliding with those navigational hazards which oftentime prove fatal and unforgiving in the real world environment.

Additional consideration should be given to those things which further provide or enhance overall scene fidelity. Just to briefly mention a few of them; aids to navigation (e.g. buoys and lighthouses must be provided to both warn the watchstander as well as provide a safe traffic scheme or "roadway" to the virtual ship's destination), current, and at a minimum, atmospheric conditions, (i.e. fog, and dusk to dawn conditions). As the system progresses throughout its various phases for development, an endless number of ideas will surface for additional features which can be added to facilitate the end goal for meeting the pre-established "intended purpose".

### 2. Representation of Geotypical Location

After having established our intended purpose, next we focused on those ports or restricted waterways most frequently transited by U.S. naval vessels. Throughout our sea-going experience, we have had an opportunity to transit a number of national, as well as, international restricted waterways. However, being assigned to NPS, it was quite apparent that San Francisco, CA offered the best opportunity for conducting both on sight research and ease of geographical access if needed. As our research progressed, we eventually made several fact finding trips in search of additional data and background materials. A number of these excursions were centered around taking selected photographs for use as textures. Their collection greatly aided in our development of an extensive texture library which is covered later in this thesis.

Several visits to the Golden Gate Bridge, Highway and Transportation District, enabled us to procure a number of items (e.g highlights, facts, and figures on one the worlds' greatest engineering marvels -- the Golden Gate Bridge), photographs of many of the well noted landmarks (e.g. the Fisherman's Wharf area -- to include Ghiradelli Square and the numerous shops and businesses located in the immediate vicinity), several tourists maps, brochures, and more importantly to experience the rich history of the San Francisco Bay area.

### 3. Truth in Representation

While considering what characteristics our system should possess in order to attain the highest possible fidelity and realism, one concept proved to be the most important of all -- deciding on the highest level of detail possible. In other words, to create the necessary environment which provides the best possible visual queuing for the inexperienced shiphandler, there must be recognizable features and characteristics within the world which the user can readily identify with (e.g. the Golden Gate Bridge, Fisherman's Wharf area, the lighthouses located at Point Montara, and SF Buoy Number One (located approximately ten nautical miles seaward)) which serves as a nautical reference for ships entering the traffic separation scheme when entering San Francisco Bay.

During our research, one interesting concept was noticed regarding most of the visual simulation systems created -- that being the fact that all were created on flat terrain surfaces.[UCLA94] [GRIN94] For their systems, which were prototypes of urban environments, this method was perfectly acceptable. However, for our application, this just simply did not work.

Once again, our requirement for the highest possible TIR required us to pursue necessary avenues for creating the shoreline -- as it relates to the outer harbor and the coast line immediately located within the inner harbor. There were a number of ways to accomplish the rendering of the terrain database features. The simplest, but most time consuming method would be to render each individual polygon in the scene using rendering toolkits such as OpenGL or even IRIS Performer. This approach could be well suited for such entertainment applications as small game(s) however, for large databases this is not suitable since it requires the programer to predetermine or precalculate each polygon vertex prior to coding the application.

#### *a. Making Use of DTED Data*

An alternate method, (and the one we chose to take), was that of making use of Digitized Terrain Elevation Data (DTED). The geographic area depicted is centered around the San Francisco Bay Area, specifically bounded between coordinates 35 degrees 55 minutes North (Longitude) and 122 degrees 45 minutes West (Latitude) NW corner and 37 degrees 25 minutes North (Longitude) and 121 degrees 55 minutes South (Latitude) SE corner. This correlates to a gaming area of approximately 25 nautical miles by 25 nautical miles, much like that of the full-scale simulator. This database was sufficient to support all training exercises which best afforded the opportunity to conduct the much needed training. However, before proceeding any further, lets take a moment to describe the features associated with DTED data.

DTED is a high demand stand alone product used in many applications which do not require Digital Feature Analysis Data (DFAD). These two products, when used together, constitute Digital Landmass System (DLMS) data. (Due to the time involved with processing the DFAD data, we chose to forego its use in the development of our system).

This DMA product is based on making use of DTED as both a terrain surface elevation model and a digital format for storage and distribution. Two different resolution models are available to DOD customers (i.e. DTED Level 1 and DTED Level 2)

***b. Current Uses of DTED by DOD.***

Today the Department of Defense (DOD) is making wide spread use of DTED in a number of applications, such as:

- Command and Control Systems
- Sensor Simulation Displays
- Automatic Height Determination
- Terrain Modeling
- Mission Planning
- Navigation Aids for Advanced Weapon Systems

***c. Characteristics of DTED.***

A data file of DTED Level-1 is a one degree by one degree cell defined by the integer one degree latitudes and one degree longitudes of a geographic reference system. Each cell contains a grid of post values which indicate elevation at fixed intervals, providing contour information for the region, figure 40. A data file of DTED Level-covers one-fourth of the area of a DTED Level-1 cell. The terrain elevation information is expressed in meters.

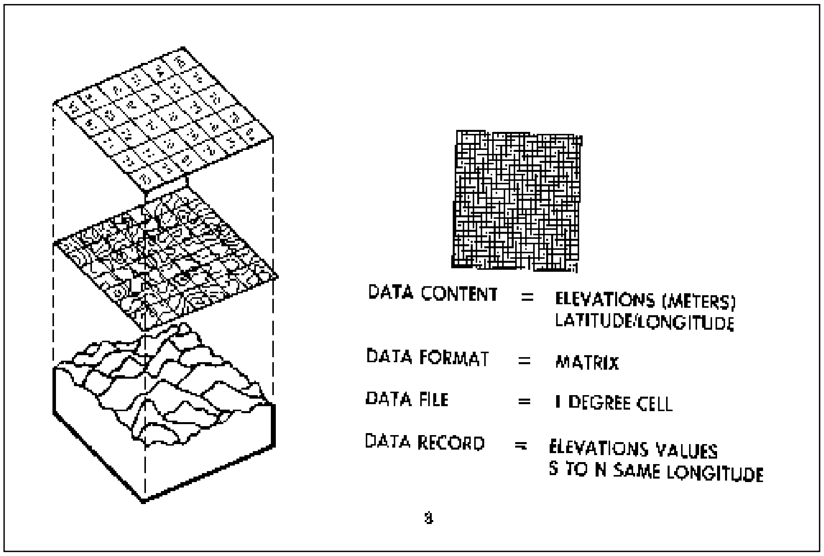


**Figure 40: Basic Specifications of DTED Data**

The elevation posts are defined by the intersections of the rows and columns within a matrix. The required matrix intervals, defined in terms of geographic arc seconds, for Level-1 and Level-2 products vary according to latitude as indicated below in Table 12.

| ZONE | LATITUDE | LEVEL-1 (APPROX. 100mPOST SPACING) | LEVEL-2 (APPROX 30m POST SPACING) |
|---|---|---|---|
| | | LAT/LONG | LAT/LONG |
| 1 | 0 - 50 N-S | 3 X 3 SECS | 1 X 1 SECS |
| 2 | 50-70 N-S | 3 X 6 SECS | 1 X 2 SECS |
| 3 | 70-75 N-S | 3 X 9 SECS | 1 X 3 SECS |
| 4 | 75-80 N-S | 3 X 12 SECS | 1 X 4 SECS |
| 5 | 80-90 N-S | 3 X 18 SECS | 1 X 6 SECS |

**Table 12: DTED Matrix Intervals**

The accuracy of the DTED data is defined in terms of both Absolute and Point to Point Accuracy in the Vertical and Horizontal Directions, figure 43. In the case of Absolute Accuracy, the uncertainty in the horizontal position of a point with respect to the World Geodetic System (WGS) caused by random and uncorrected systematic errors. The value is expressed as a circular error at the 90% confidence level.

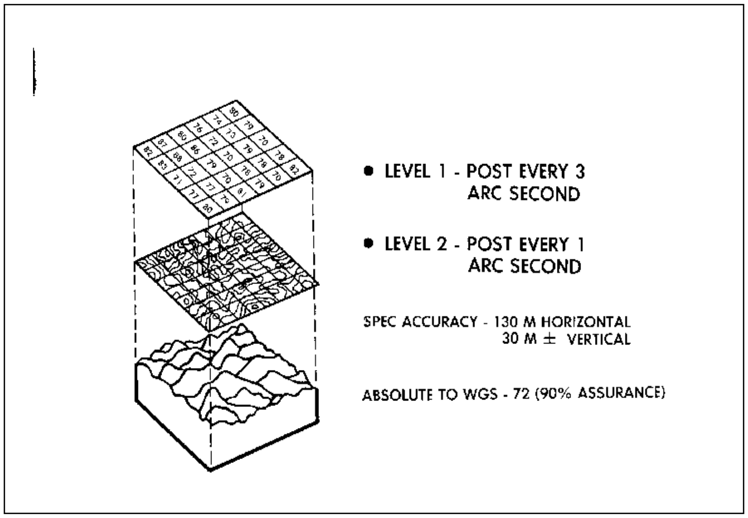


**Figure 41: DTED Accuracy Definitions**

Figures 43 and 44 also illustrate the basic characteristics and specifications of DTED Levels 1 and 2. As alluded to earlier, DTED consists principally of the Data Content - which is simply the elevations , Data Format - which is in the form a matrix arrangement of terrain elevation values at specified increments of latitude and longitude (the specific increment depends upon the latitude), Data File - consisting of a one degree by one degree area of coverage, and finally the Data Record - consisting of elements that are evenly spaced in latitude and longitude at the interval designated in the user header label in South to North profile sequence

Specifically in Figure 42, we see the Accuracy Definitions (horizontal and vertical) for DTED Levels 1 and 2. Remembering that the greatest level of detail can be found when using Level-2 data, which has a post spacing of 30 meters vice that of 100 meters found in Level-1[DMA86].

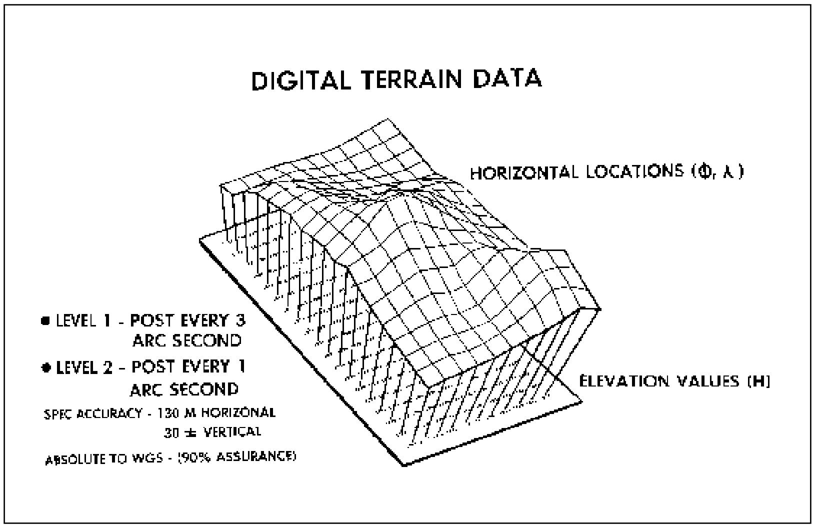


**Figure 42: DTED Data Characteristics**

For information regarding the actual conversion process of raw DTED data to flight (.flt) format for use in this project, see Chapter VI - MultiGen: A Dynamic 3-D Modeling Tool.

### *d. Researching the Location*

While still within the earlier stages of the design phase, there became a point at which the need to visit the geotypical site -- San Francisco became important. As mentioned earlier, nothing that we knew could replace the experience of traveling the streets of San Francisco, visiting a myriad of historical landmarks such as Alcatraz Island, the Transamerica Building, Fisherman's Wharf, Pier Thirty-Nine and actually touring the Golden Gate Bridge, along with many geospecific locations within the immediate vicinity of our target area.

Additionally, this enabled us to take 35mm and digital photographs using a Canon AE-1 and Apple QuickTake 100 digitizing camera. With respect to the required film exposure available for use with the 35mm camera, it appears that 100ASA color film was quite suitable for taking photographs which once again provided us with a portfolio of over 100 photos. In doing so, we additionally accomplished the task of collecting photos which enabled further development of our texture database.

The numerous pieces of historical data (e.g. banners, post cards, brochures, maps, visitor's information packages, and first hand knowledge from professional tour guides) would add later on to the development process.

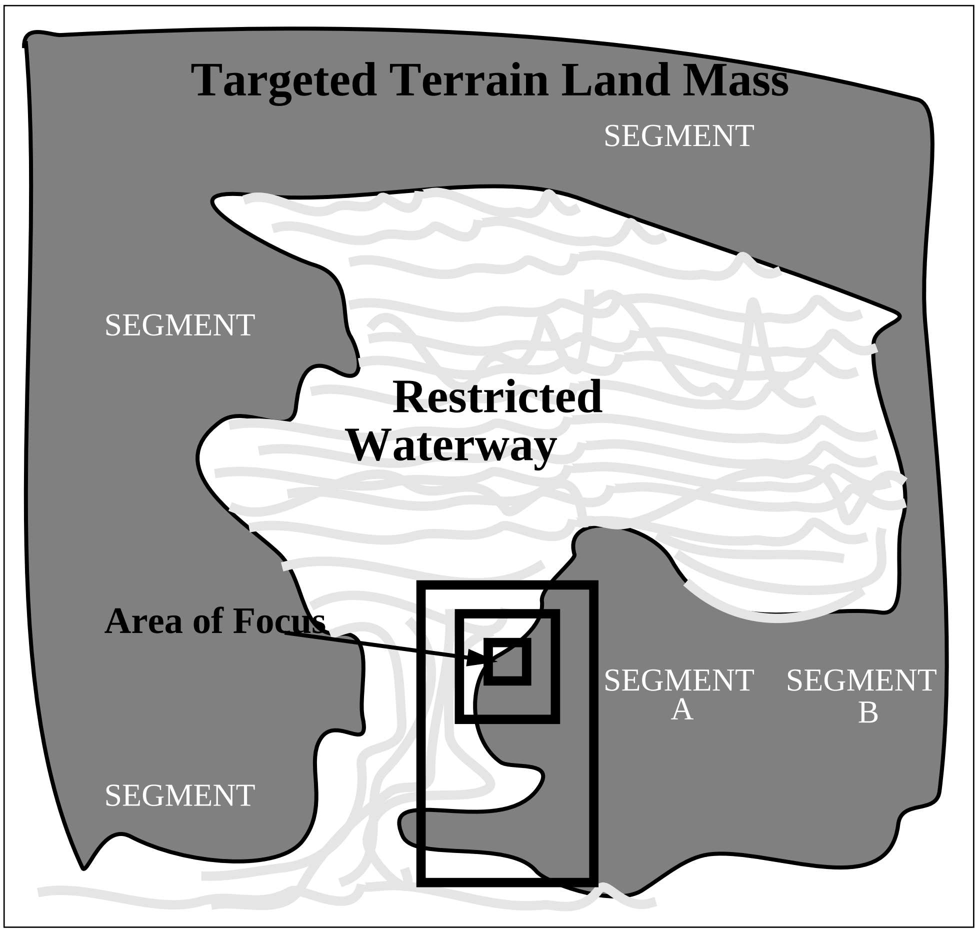


**Figure 43: Description of Subdivision Technique**

### *e. Consider the System Being Modeled*

After looking at our simulator system on a macro level, we later proceeded to breakdown it down into individual cells or segments in a similar manner used by

[AIRE94]. This took quite a bit of time, howver, it enabled us to further focus in on and plan for those areas that were going to require the highest degree of TIR. Once this was done, we would later begin, in very meticulous fashion, to identify those items or icons which would aid us in creating our database, with once again the goals of creating the highest degree of scene fidelity and TIR possible.

In Figure 44, an illustration of the targeted areas of interest is presented. Using this image of the area, we began segmenting the terrain or geotypical area into a number of segments or cells. Once again, this was a similar method or technique employed by Airey, Rohlf, and Brooks [AIRE94], to divide model space or equivalently, viewpoint space, into cells.

For our research effort, this concept served a twofold purpose. First, it allowed us to define the union of visible polygons for all the viewpoints in a segment as the potentially visible set for that segment. For any viewpoint in the segment, rendering the potential visible set for that segment generates an image with no missing polygons. Given the fact that the size of the potentially visible set is usually smaller than the size of the entire database it was derived from, it will take less time to render. Secondly, after subdividing the terrain into these segments, we were now able to manage both our modeling and texture database development efforts more efficiently. In fact, this lead to the development of a number of what we consider to be design axioms. These axioms would prove to serve us well, as we move further into our development phase of the research. To briefly state these design axioms, they are as follows:

- Axiom 1: Keep in mind the geographic scale you're working with and always minimize the size of the potentially visible segments. The larger the geographic area (e.g. an area the size of Fisherman's Wharf covers a little less that a 1.5 square miles) the larger your modeling efforts will become to develop the necessary structures to fill it. (There are numerous structures located within that area).
- Axiom 2: Remember what your intended application is and subdivide your terrain accordingly. Make the area of focus become the origin of your design and then

expand your modeling efforts from here.

- Axiom 3: Identify as many recognizable major landmarks as possible. This also enhances the goal of obtaining the highest level of TIR possible.
- Axiom 4: Don't duplicate modeling or texture design efforts. Once you've created a particular number of specific structures, create instances or clones for other segments in the database.

#### *f. Identify Development Tools*

Unlike earlier years when virtual environment technology was in its infancy, today there a host of highly sophisticated development tools available to enhance the overall development process. Each offering a very diverse technique for developing almost any virtual environment database system. Much research continues in the area of designing even more compact and specialized applications, with some even being designed to be fully automated throughout the entire modeling process [KOCH93]. Such systems will be completely responsible for design and/or articulation. Their main characteristics will include:

- Being completely responsible for one or both aspects of the modeling task.
- The userwill be passive, with respect to one or both aspects of the modeling task.

However, we are currently still making use of very dynamic and capable three dimensional modeling applications which as stated earlier, enhanced every aspect of our design and development effort.

The following applications were readily available to us -- MultiGen (.flt format files), Wavefront (.oft format files), and AutoCad (.dxf format files). Although each fell on the lower end of the interaction paradigm [KOCH94] for graphical-object modeling, together they still managed to serve as viable tools for aiding in the development and completion of our system. For more information regarding the capabilities of these applications, see Chapter VI.

#### g. System Capability

This was perhaps the easiest decision to make during the design phase of the project. What made it so, was the fact that we already knew beforehand and subsequent to our after visiting the full-scale simulators currently being contracted by the Navy, what their unique characteristics were. Our task was to model as many of those same features and additionally to incorporate them into our own design. The full-scale simulators possessed the following capabilities:

- The ability to network any or all four simulators to allow for interaction in the same scenarios, simultaneously.
- Mutual sharing of established hydrographic data bases.
- All full mission bridge and wing simulators possess twice the vertical coverage of current shiphandling simulators.
- Bridge wing and full mission bridge simulators have perspective to develop “seaman’s eye” for alongside shiphandling.
- The ability to provide for “hands-on” training for teams of four students at a time.
- Provide different ship types.
- Real-time interface capability.
- To provide appropriately challenging scenarios for maneuvering in restricted waters, anchoring, mooring, formation and underway replenishment work, and special evolutions.
- To provide refresher and transition training in shiphandling to enhance experience level.
- To simulate external factors and forces (e.g. day, night, dusk, reduced visibility/ fog, wind, current, bank and channel effects, ship interaction, and aerodynamic forces.
- To provide multiple simulated geographic areas (e.g. Charleston, SC, San Diego, CA)
- To provide a large exercise area for the maneuvering
- To enable multiple ships to be underway simultaneously
- To allow for post-exercise feedback

Refer to Chapter III for additional information regarding the system developed during this research.

#### h. Environmental Effects

As in the case with the full-scale simulator, we felt that our system should possess in every detail those environmental characteristics or effects which would enhance overall fidelity and create the maximal sense of realness and training effectiveness that rich scene content can provide. To accomplish this we made use of several of Performer's visual simulation (libpf) and low-level rendering (libpr) library functions to produce fog and a realistic daylight and evening horizon which are essential conditions experienced by shiphandlers when underway.

- Fog. Fog is generated using the pfFog function in the rendering library. The conning officer is allowed to control the range of the fog from the eyepoint from a distance of 1 meter to 10,000 meters. Upon selection, the default range is 2000 meters. The fog color is blended with the color that is computed for rendered geometry based on the geometry's range from the eyepoint.
- Dusk effects. Realistic dawn and dusk scenes (night and day) are displayed based on the light intensity level entered by the conning officer. RGB values for the color of the top of the sky, bottom of the sky, horizon, and ground are calculated based on the light intensity selected by the conning officer to give the effect of a red sunset and a pink sunrise along the horizon.

If the light intensity value falls below (or rises above) a certain threshold (in this case 0.6 for dusk/sunrise), the fixed object models switch their geometry from unlighted (daylight models) to lighted (nighttime models).

This technique became quite labor intensive from a modeling standpoint in that, for each day model (e.g. the Golden Gate Bridge), there had to be at least five levels of detail also modeled, moreover for each night model, the same number of levels of detail also had to be developed.

#### i. Texture Database Design

As addressed by Michael Jones in his paper [JONE94], the significance and importance of texture mapping in realistic visual simulation and entertainment applications cannot be overstated. Texture processing is arguably the single most important incremental capability of real-time image generation systems. The presence and sophistication of texture processing continues to define the “major” and “minor” leagues of visual simulation technology.

In other words, it does not matter how awe inspiring the system we designed and developed is, we understand that the real marketing of it comes about as a result of our effective planning for the development of a dynamically rich texture library. This we feel, is exceedingly critical to the successful implementation and credibility of our system.

At this particular point in our research, there was one key fact that we surmised - that being that there were a number of ways to develop a rich texture library. However, during this particular phase of design, we returned back to one of our originally established precepts centered on “truth in representation”. Given the importance of this particular design issue, we have chosen to treat its content in an entire chapter of its own. Refer the section in Chapter VIII concerning texture database design.

#### *j. Model Management*

The issue of model management is perhaps the second most important design issue faced in the development of any simulation database. From the standpoint of production man-hours, modeling -- the process of creating graphical objects -- consumed the majority of the human effort invested in the entire project. It is worth mentioning several contributing factors to this particular point.

First, we possessed very little experience in the use of the modeling tools used -- MultiGen. This called for learning the application from the ground up, invariably resulting in our overcoming a tremendously steep learning curve. Overall the time spent to do so was not wasted, however, to accomplish the amount of work displayed in the final product, there was a significant amount of trial and error spent developing and conceptualizing the required database objects.

One significantly important concept of modeling design and development was discussed by Kochhar, Marks, and Friedell [KOCH94], which states that the actual modeling process involves a combination of two different activities -- articulation and design (Eq 7.1). With design, being the more creative and inventive aspect of modeling, while articulation, was defined as being the activity of providing a precise graphical description of an object model, given its conceptualization [KOCH94].

$$\text{MODELING} = \text{DESIGN} + \text{ARTICULATION} \qquad \text{(Eq 7.1)}$$

As alluded to earlier, the second contributing factor to our inordinate number of man-hours being spent on modeling, was due to the need to meet our previously design objective of attaining maximal truth in representation. The pursuit of this objective called for considerable research in to the characteristics and cultural features associated with the geotypical/geospecific location (i.e. San Francisco).

# IX. SYSTEM USABILITY SURVEY

## A. BACKGROUND

Upon the completion of system development, we discovered that we had sufficient time to fulfill what can be considered one of the more neglected facets of computer software design - system functionality and usability testing. This endeavor is in keeping with the recommendations setforth by the National Academy of Sciences [NAS95], which strongly recommends that, "the federal government help coordinate the development of standardized testing procedures for use across studies, systems, and laboratories...". As designers and developers of computer software systems, countless hours can be spent designing and testing applications. Given today's rapidly growing user market, it is not unlikely that the experiences of the developer may prove to be irrelevant, and that the developer's intuitions may be somewhat outdated or inappropriate. The central focus of such an analysis should not be to only conduct a close examination of the overall user system interaction, but additionally, and perhaps more importantly, to aid in the development of future design criteria and more intrinsic design goals.

Our research in this area offered a unique opportunity - in that we were able to identify and attract a relatively homogenous group of participants who would have easy access to the test site as well as provide us with a myriad of background experiences and insights on what the final system should look like. Although collected after the completion of the prototype's development, it is our hope that the information resulting from this study will aid in future development and improvement in those areas identified by it. The following are a few of the areas we chose to target for evaluation by our sample group. The analysis focused specifically on those skill level functions currently found in the full-scale simulators contracted by the Navy:

- Identifying and redefining those user based tasks which are critical to the development of competency based objectives. Specifically those shiphandling skills which enhance the development of shiphandling in restricted waters. A comparison of those features found in the full-scale simulation system versus our Level - 1 prototype can be found in Appendix G.

- Establishment of usability study methods or guidelines unique to virtual reality based simulation systems.
- Identifying potential problems as they relate to the logic in sequential performance of competency based tasks.
- Troubleshooting our users guide or documentation.
- Identifying and addressing those task and functions that users felt were important enough to enhance system training capability.
- Developing a user-centered design framework for future system development.
- Establishing specific design and development axioms which can be applied to those situations requiring rapid prototyping of virtual simulation-based environments.
- Ensuring basic task conformance to Naval Standards.
- Refining future design of system interface and documentation.
- Identify potential problems.
- Verify new solution ideas.

This deployable shiphandling system offers tremendous potential for future use in an infinite number of naval applications. This fact was further supported by the results of the survey. As the participants became more involved with the system, their ideas for future application and enhancements grew by leaps and bounds. Many of these ideas were repetitive in nature, however, they served to support our belief and feeling that we had in fact been headed in the right direction with our design.

One key fact we found ourselves repeatedly stressing to members of our sample group, was that the system was merely a “prototype”. Our intentions were not to compete with the full-scale mock-ups currently being contracted to the Navy by Marine Safety International (MSI). On the other hand, we came away with a strong belief that the accomplishments attained by virtue of this research project, will invariably aid in guiding the United States Navy toward perhaps considering the real possibilities and potential for accelerated training opportunities in the area of virtual simulation systems. Additionally, it is our hope that this research project provide an introduction into the important arena of providing smaller scaled virtual systems at reduced cost yet equal if not more capable systems in larger quantities to those units in need. The prototype developed from this research and usability study for the first time offers a direction for future development of alternative low-cost and portable training vehicles which can significantly enhance the future training of the Navy's young junior surface warfare and submarine officers. Their success as shiphandlers will hinge on the leadership's ability to recognize the necessity and timely exposure to this latest simulation technology and will to make it available at a much earlier period in their careers rather than later because of limited funding and resources.

## B. DESCRIPTION OF THE METHOD

The design and development of computer software systems has become more highly emphasized and complex in today's rapidly growing computer science field. There is an ever increasing need to develop sound design axioms and guidelines which will serve to aid both system designers, as well as developers, in controlling the overall design and development processes. The increased importance is even more evident by recent developments in such areas as entertainment, medicine, training, and most recently the new found application of virtual reality.

We began our thesis research with the single purpose of developing a portable deployable virtual simulation-based shiphandling trainer. This fulfilled one of the principle goals of software design and development - that being to identify a real need or problem. As revealed by the safety data obtained from the Naval Safety Center, we were not only able to identify the need, but additionally, were able to identify specific areas for targeting our design and development efforts. Once again stated, our primary focus became to develop a system which principally focused on the development of shiphandling in restricted waters.

Typically, a usability inspection is aimed at finding usability problems in an existing user interface design, and then using these problems to make recommendations for fixing the problems and improving the usability of the design. This means that usability inspections are normally used at the stage in the usability engineering cycle when a user interface design has been generated and its usability (and utility) for users needs to be evaluated.

"Usability inspection" is a generic term for several methods. Of these we chose to make use of two of the more prominent methods being used to evaluate computer software systems today - Heuristic Evaluation and Cognitive Walkthroughs [NEIL94]. Below is an abbreviated description of each method and its applicability to our research.

Research shows that no matter how analysis has been done in designing an interface or software system, there will always be problems that only appear when the design is tested with users. Given the fact that we were the developers of the system, we felt that our knowledge and backgrounds could somehow skew the makeup of this important document. The testing with the users will always show some problems with the design. As designers, we sought data that we could look at such that we could balance costs of correcting the more severe problems, then revise the interface and retest in later revisions.

### 1. Heuristic Evaluation Method

The Heuristic Evaluation method is the most formal method of those available. It involves having usability specialists judge whether each dialogue element conforms to established usability principles. These principles generally are rules of thumb that can guide design decisions. Understanding beforehand that heuristics were not considered to necessarily be a task-oriented evaluation technique, according to [NIELS94], heuristics can be an important part of task-centered design. To offset this shortfall, we additionally chose to make use of the cognitive walkthrough method (to be discussed later in this chapter), which is a strictly a task-oriented method.

#### *a. How The Heuristic Analysis Approach Works*

The procedure is based on the observation that no to single evaluator will find every problem with an interface, and different evaluators will often find different problems. So, the procedure of the analysis is this: Have several evaluators use the ten heuristics to identify problems with the interface and system overall - in this case our Level-1 prototype. Each evaluator should do the analysis alone. Then combine the problems identified by individual evaluators into a single list. Combining those problems identified by the individual evaluators into a single. In the case with our prototype, the result listing can be found in Appendix F.

As proven by [NIEL94], the combined lists of interface problems includes many more problems than a single evaluator would identify, and even with just a few evaluators, we could have attained sufficient data which identified the major problems with the prototype. One side benefit of this method, was that we were able to attain data regarding less critical problems that only slowed or inconvenienced the user.

There are 10 basic items which the method targets. Many of these were addressed mainly in Section 3.0 of the survey instrument. A final analysis of the data derived from the study can be found in Appendix-G.

- Simple and Natural Dialogue
- Speak the Users's Language
- Minimize the users' Memory Load
- Consistency
- Feedback
- Clearly Marked Exits
- Shortcuts
- Precise and Constructive Error Messages
- Prevent Errors
- Help and Documentation
- (Additional information regarding this listing can be found in Appendix D.)

**2. Cognitive Walkthrough Method**

The Cognitive Walkthrough Method, focuses on evaluating a design for ease of learning, particularly by exploration. This focus is motivated by the observation that many users prefer to learn software by exploration. Instead of investing time for comprehensive formal training when a software package is first acquired, users prefer to learn about its functionality while they work at their usual tasks, acquiring knowledge of how to use new features only when their work actually requires them. This incremental approach to learning ensures that the cost of learning a new feature is in part determined by the feature's immediate benefit to the user. One key factor must be considered though - the background experience and general knowledge of the user can aid tremendously in developing specific tasks, which be used to measure system effectiveness with the cognitive walkthrough methodology.

According to [NEIL94], prior to making use of this analysis method, four things are required.

1. A description of the system or prototype that will be evaluated.

2. A brief description of task the user is expected to accomplish. To enhance the effectiveness of the analysis, it is best to identify those task which the user already possesses some experience or general knowledge.

3. A complete written list of the actions needed to complete the task with the interface or prototype. Task selection should be based on the results of marketing studies, need analyses, concept testing, and requirements analyses.

4. An idea of who the users will be and what kind of experience they'll bring to the evaluation or usability study.

To meet these four basic criteria, we chose the format of an exercise scenario - which is oftentimes the preferred method for applying the cognitive walk-through method. Keeping in mind that there were also four basic questions that had to be considered in its design. The below listed questions served as guideposts for development of the task incorporated in the exercises in Section 5.0 of the instrument (refer to Appendix C: Usability Inspection Survey Instrument). They were:

1. Will users be trying to produce whatever effect the action ask for?

2. Will users see the control (button, menu, switch, etc.) for the action?

3. Once users find the control, will they recognize that it produces the effect they want?

4. After the action is taken, will users understand the feedback they get, so they can go on to the next action with confidence?

As evident by the task performance objectives stated in Section 3.0, all tasks specific to the Navy's requirements of shiphandling in restricted waters were addressed. A complete listing of current training objectives being taught at the full-scale training simulators can be found in [MSI94].

## C. INSTRUMENT DESIGN AND FOCUS

### 1. Evaluating The Evaluators

After considerable thought and effort was made to develop on paper a plausible evaluation instrument, the next step was to intergrate each analysis technique in with any and all other important objectives. Considering the fact that we needed to varify the experience level as well as level of knowledge of each evaluator, we chose to create a series of questions centering on both their experience as shiphandlers as well as an equally important area of expertise or skill level with computer systems. In other words we sought to develop a user profile on each of our evaluees which would better aid us in answering questions which may have arose subsequent to the evaluation period.

Given the fact that the prototype system was workstation based and could only be directly manipulated by a mouse, it was important to determine the level of comfort each user had with such a peripheral. Several questions can be found in Section 1.0 of the instrument which directly address each users background and exposure to such system interfaces.

The area we chose to focus on with respect to the computer experience was centered on their overall knowledge of the current terminology and or jargon being tossed around in their day-to-day interaction with computers. We provided a listing of over a half dozen computer related terms such as virtual reality, immersion, direct manipulation, as well as asked several questions with respect to computer technology in general so as to gain some idea as to the users disposition or attitude about computers as a whole.

In the area of shiphandling experience (Section 2.0), we sought to not only gain information regarding the evaluators skill level and experience in this area, but also to determine their disposition or attitude about both the training they received and to stir some reflection on their past experiences as young shiphandlers. Our interest was in gaining a feel for who (i.e. commanding officer or superior) played the greatest role in the development of their skills as a shiphandler. Equally important, we wanted to have the evaluator reflect back on past experiences and offer up comparisons between the single most positive commanding officer who contributed to their shiphandling development and the one who either hindered or who had little or no impact on their development. To go one step further, we asked the evaluators to provide specific characteristics which they felt made these commanding officers such positive influences on their development.

**2. Task Performance Objectives**

Section 3.0 of the survey was designed to be accomplished at the conclusion of the evaluation period. As alluded to earlier, we examined the current training and goals established by the Navy and are currently being taught at both its Newport, RI and San Diego, CA simulation training facilities.

As delineated in the survey instrument, each task was considered and tested during both the development of both the system as well as during the development of the Exercise Scenario(s). The specifics of the task can be examined in Section 3.0 of the instrument (refer to Appendix C).

The exercise scenario portion of the instrument (Section 5.0) consist of a basic description of a real world situation or experience. Prior to commencing the session, each evaluator received a 15 to 20 minute briefing on the specifics of the entire instrument with specific emphasis on the system functionally, the instrument, and in a word a navigational briefing consisting of the current location, navigational picture and task performance required throughout the evaluation period.

In Section 5.0, each evaluator was placed within a portion of the restricted waterway of the featured database. This was done so as to allow each of them to gain some relative bearing with respect to the geography (the local terrain). In the case of our scenario, the local operational area was in and around the San Francisco Bay area.

One point we failed to mention earlier regarding the conduct of the exercises. The system we developed although it was not a principal focus of our development, was in fact networked (See Chapter Seven: Network Implementation for a more detailed explanation on how we were able to intergrate the system into a DIS Networked environment). This capability further enhanced and extended the bounds of our principal focus of single unit restricted water operations. With this capability, we were able to also incorporate additional tasks which focused on the additional shiphandling task of:

***a. Shiphandling in Open Ocean which includes:***

Operations while in battle group formation

Restricted visibility imposed

Traffic vessels imposed

Maneuvering own ship in replenishment operations

Making approach to replenishment ship

Station keeping alongside.

***b. Shiphandling in Mooring Evolutions:***

Getting underway from pier or anchorage

Transit to pier

Pier approach

Mooring to a buoy

***c. Participation in Multiple Ship Operations:***

Conduct of Search and Rescue Operation

Formation Steaming

Intership Communication Methods

As the scenario progresses, each evaluator is given a series of predesignated task to accomplish with the understanding that the entire evaluation from start to finish will take approximately ninety minutes to complete. Given this fact, nearly all evaluees felt confident in their ability to complete the assigned task in far less time than was normally allotted. In fact, the survey results showed that only two out of the twenty-four evaluees ever completed the session on time. Reasons given for this are presented in Appendix F: Users Comments. The most frequent reason given for failure to complete the exercise task/ scenario was:

(1) The system was more than they had expected. In other words, the evaluees expected the system to be more like a computer game, but found that when performing certain task, that in most cases their ability to perform certain basic shiphandling skills had in fact diminished in the months and in some cases years that they had been away from an at-sea assignment.

(2) The level of detail in the models and the database as a whole was so esthetically appealing that they loss sight of the amount of time they had been involved in the performance of some the required task.

(3) The immersive quality (especially during the reduced visibility portion of the scenario) really carried them away to a time when they had actually been in those situations. (These and many other comments can be found in Appendix F.)

### 3. The Post-Evaluation Period

As mentioned earlier, Section 3.0 addressees those items of interest which address several other key areas regarding the prototype's functionality and features. Specifically, evaluees were to evaluate the system with respect to its appealability. They were asked to rate their overall impression of the system.

Two additional areas evaluees were to consider were the Display Screen along with the Terminology and System Information. Evaluees were to evaluate the arrangement of the GUI's or control panel and additionally consider such things as screen real estate use. Grouping and meaning of items and their labelling. Phrasing of menu items and graphical layout and design. Additionally, questions were asked which targeted the choice of specific selection mechanisms and item presentation sequence.

The third area of focus was in the area of Learning. Here the evaluee was asked to evaluate such issues as the degree of difficulty experienced when learning to operate the system and the amount of time required to learn to use it. The accomplishment of task performance and the degree of comfort they felt to adventure out in order to experiment in the discovery of new and different features of the system.

Finally, evaluees were asked to rate or evaluate the system's capabilities with respect to its visual layout, minimization of user's memory load, speed, and information displayed. Given the information obtained regarding the evaluees computer background experience, this area might prove to be invaluable and to provide some degree of credibility to the responses provided in this area. By and large, users responses to the questions in this area were good and in keeping with what we expected along the lines of students here at the Naval Postgraduate School.

## D. SAMPLE GROUP

The real significance of this functionality survey is that it is the first time that a usability study has been accomplished as a result of thesis research, which led to the design and full implementation of a networked virtual simulation system by the original designers and developers within the same being period of research. It goes without saying that there were probably several mistakes made resulting from a lack of experience with both designing and conducting a usability analysis.

In order to establish the highest degree of credibility for our system design, as well as, our survey data, we felt that it was imperative that we identify a nearly homogenous test group. We established a basic user profile of which possessed a distinct profile of some one who would use the system rather than seeking to just have a mixture of users evaluate the system. To have taken the later approached would have required us to spend an inordinate number of man-hours trying to extract pertinent data for members of these two groups. Thus, our established user profile consisted principally of (in the order of preference) first, Surface Warfare Officers, followed by Submarine Officers. The reason for this was due to several factors with the primary one being a result of the far less amount of actual shiphandling experience possessed by submarine officers when on the surface. As was mentioned in the safety data presented in Chapter One, submarines when compared with afloat combatants were fourteen percent more likely to be involved in collisions at sea. One primary contributor for this is due to the lack of opportunities to exercise their shiphandling skills when on the surface.

Our total user population size was twenty-four naval surface and submarine officers, of which two were international students and one female. The survey revealed the average rank of the participants to be in the paygrade of Lieutenant (O-3) with 3.9 years being the average amount of at-sea experience. The average time in service was 4 to 5 years with at least 1.7 sea tours completed. Eighteen of the participants came from the surface warfare community with the remainder being from the submarine community. The average age for the group was 29.2 years of age. The most recent at-sea experience was less than 0.9 years.

Three of twenty-four participants were found to have had some exposure to formal simulation training. Five had very limited experience to computers, while three were found to have never owned a computer. Overall since reporting to NPS, all participants were found to some computer experience. Of the participants, thirteen were found to possess PC-based computer software - war game in nature. When asked their comfort level with computers, only one reported fairly comfortable while two reported themselves as being experts and the remainder describing themselves as being very comfortable with the technology.

When asked about the amount time actually spent driving the ship during underway, the numbers varied from 10 percent to a high of 30 percent. None of the participants had ever received an award for their shiphandling skills. There was one female surface warfare officer who participated.

## E. EVALUATION RESULTS

Much of the data which follows can be found in Appendix G: Usability Study Data. Due to large number of questions asked in the survey instrument, only a select few have been chosen for review and discussion at this time. The actual numbers which reflect the Mean, Standard Deviation, and Standard Deviation of the Mean are presented in Appendix H: Usability Study Data.

### 1. Section 3.1 - Overall User Reactions

In this area evaluees were asked for the overall impressions of the system. The following discriminators were used:

1. Concerning the system's overall impression, Terrible (1) to Wonderful (4):

Seventeen evaluators rated the system a four, while the remainder rated it a three. The mean was 3.71.

2. Concerning the use of the system, Frustrating (1) to Satisfying (4):

Fourteen evaluators found the system to be satisfying rating while nine rated the system a score of three. The remaining users rated it a value of two. The mean rating was 3.58.

3. Concerning whether or not the system was considered to be Dull (1) to Stimulating (4):

Seventeen of twenty-four rated the system as being Stimulating a score of four, with six evaluators rating it a three and only one rating it a score of two. The mean was 3.67.

4. Concerning the degree of difficulty in operating the system, Difficult (1) to Easy(4):

There was an even split among evaluators. Twelve rated the system as being Easy to operate while the other twelve users rated the system with a score of three somewhat lower. The mean was 3.50.

5. Concerning the amount of power possessed in the system, Inadequate (1) to Adequate (4):

This was an interesting question to many evaluators in that there was perhaps some misinterpretation in what was meant by power. Many thought that the question referred to the capabilities of the system's (i.e. its functionality or ability to fire weapons, or to possess sensors), while others thought the question referred to the computing or processing power. Regardless, of the interpretation, sixteen felt that the power was adequate, while five felt that the power was somewhat less than adequate, with only one scoring the power in the two range. The mean was 3.50.

6. Concerning the smoothness of operation and interface, Rigid (1) to Flexible (4):

Fifteen evaluators felt the interface for operating the system could be considered Flexible while eight felt that the system deserved a score of three and only one felt the system was a bit more less flexible by rating it a score of two. The mean was 3.58.

The overall rating of the system in this area received a mean score of 3.59.

**2. Section 3.2 - Display Screen**

In this area, we asked evaluators to rate the system regarding the functionality, design, and appearance of the screen and the its components displayed on it.

1. Characters on the screen, Hard to Read (1) to Easy to Read (4):

Users had mixed feelings regarding their ability to read the display data. Only nine rated the display as being easy to read, while ten rated the display of the characters as being a little less than easy to read. However, there were five of the evaluators which felt that the display of the characters was less that fifty percent. This equated to two rating this particular characteristic as being too hard or difficult to read. The mean score was 3.08 overall.

2. Arrangement of control functions, Poor Placement (1) to Good Logical Placement (4):

Evaluators once again considerably split in all areas. Eleven rated the arrangement of the functions as being logical, seven somewhat less, while the remaining five evaluators were further split in the remaining areas - three and three. The mean score once again was 3.08 overall.

3. Control Widgets, Confusing (1) to Clear (4):

This was the lowest scoring area in the entire survey. It was by far the lowest among those questions regarding the screen display. Seven evaluators rated the control widgets as being clear, nine as somewhat less clear, and eight even more confusing. We can possibly contribute this to the fact that over less than fifty percent of the evaluators were from the Computer Science Curriculum and subsequent questioning revealed that a number of the users were not familiar with the operation of widgets, in this case specifically slider widgets. A number of evaluators commented that they would preferred joysticks to the widgets (in particular the sliders). The mean was 2.96.

### 3. Section 3.3 - Terminology and System Information

In this area all questions scored considerably high with the range of scores being from a low 3.54 to 3.96. Due to the favorable results in this area, we will limit our comments to the two lowest scoring areas

1. Performing an operation leads to a predictable result, Never (1) to Always (4):

Although the breakout was not unusual, users were somewhat split regarding the responses they expected from the system when they had executed or manipulated a particular widget or function.

Fifteen felt that the responses were always predictable, while seven felt that they were a bit less predictable and only two felt rated the system a score of two. The mean score for the question was 3.54.

2. The other low scorer of the group was regarding the question of terms on the screen, Ambiguous (1) to Precise (4):

Users overwhelmingly felt that the terms used on the screen were precise in their meaning as well as, their response. Overall, users evaluated the terms on the screen as precise (a score of four). The remaining users rated the system a three. the mean rating was 3.88.

### 4. Section 3.4 - Learning

This particular area addresses the ability of the evaluator to learn how to use or operate the system. Like the previous area, all scores were considerably high, with the range being from a low of 3.75 to a high of 4.0 in four of the nine question areas.

Here we'll examine only those questions which receive scores or responses which greatly out of the norm or range of the majority of the scores. For instance in questions, three and four, evaluators responded far to the left in these areas. We want to search through the data to find out if possible why they did so.

1. In question three, Time to learn to use the system, Slow (1) to Fast (4):

An astonishing twenty-three of the twenty-four participants rated the system as a four. In other words, the system was easy to learn and the time to learn was extremely fast. Evaluators felt that the system was quite intuitive which made for ease in learning. Only one individual felt the process was of learning the system was slow. In fact, when questioned, this particular user felt that this would be the perfect trainer for developing the basic skills of any junior officer regardless of level of experience or background. The user also confided that they had received very little opportunity to drive or handling the ship at their last command and that they felt that they would be at an extreme disadvantage upon returning to sea as a department head.

2. In question four, once again the evaluators rated the system quite favorably. Twenty-One of the twenty them felt that through the design of the system, it encouraged them to explore other features through trial and error. This is an interesting response in that for the most part, the average junior shiphandler oftentimes feels restricted in their ability to really test out specific maneuvers or techniques. In many circumstances, more often than not, the young officer finds him/herself in a position where they will serve as the relay for the commanding officer who is less confident in his/her abilities as a shiphandler and that of their subordinates.

This sort of attitude transcends into fear and apprehension. Thus, when these officers are placed in a position or situation requiring them to respond under stress, they often don't or take unnecessary risk founded on a hunch rather than on experienced.

Once again one of the remaining three evaluators rated the system as discouraging, while the other two rated the question a three. When questioned, it was not surprising that the respondent for this particular question was the same for question three. This evaluator felt that much of the apprehension stemmed from the lack of basic shiphandling skills and a severe lack of confidence in their abilities as a ship handler.

Overall the section received a rating of 3.90.

### 5. Section 3.5 - System Capabilities

This particular area was designed to evaluate the overall capabilities of the system with respect to its hardware, software, and peripheral configuration. Here we've chosen to reverse our focus on the areas that scored the lowest in the section overall and examine some of the higher scoring questions for reasons why evaluators felt they deserved the higher ratings.

1. System speed, Too Slow (1) to Fast Enough (4):

For overall system speed and performance, twenty-four of twenty-four users felt that the system was certainly fast enough in all respects. Through the exercise period, the system performed consistently at a minimum of fifteen to seventeen frames per second.

2. Novices can accomplish tasks knowing only a few commands, With difficulty (1) to Easily (4):

Twenty of 24 evaluators felt that the system was easy and user friendly enough so that even a novice could learn to use it in record time. The next lowest rating was a three, where the remaining four evaluators felt the novice user could be easily used the system ease. The mean for the question was 3.83.

3. Are the needs of both experienced and inexperienced users taken into considerations?

Eighteen evaluators rated the system a four in this particular. The remaining six evaluators were spread across the spectrum, in that three rated the question a three, two rated it a 2 and one rated it a one.

## F. SUMMARY

Once again the purpose of this usability inspection survey was to provide a meaning instrument for future design and development of this Deployable Shiphandling Simulator System. When reviewed, it will assist future developers in identifying future system modifications which will enhance overall system functionality.

The data gathered from this survey has already identified several areas which should receive consideration for future development. Based on this data, there remains much need for improvement in the some of following areas:

- Visual Layout - Specifically, users feel that the system's layout can be improved by reducing the number of slider widgets and implementing more representative instrumentation type widget which includes a dial or gauge display. This would be more like the instrumentation found on the helm consoles of most U.S. Naval vessels.
- Provide More Help Features - Currently there is limited if any help functionality. The system as was brought out by the survey is highly intuitive. Thus, users generally don't require much additional help. However, if the system is to become a stand- alone virtual simulation with any real merit, it must possess a more

dynamic help system which allows even less supervisory involvement during the earlier stages of user development.

- User Customization - One point that was repeatedly brought out was the fact that there should be more traffic or shipping added as the experience level of the user increases. Users would like to be able to ingest more challenging maritime situations than the system currently offers.
- Support of Additional and Better Interface Devices - One areas that users felt the system could be improved was by limiting the use of the mouse as the primary manipulation device. They felt that the use of such peripherals as joysticks and throttle type controls would be more realistic and responsive than the current mouse.

This supports our original premise regarding the introduction of an HMD interface into the system. This would further enhance the already powerfully immersive qualities found in the system. (Refer to Appendix F for a review of these and many other user comments.)

In closing, it has been terribly exciting to have been associated and a part of the development of such a potentially dynamic simulation system. It was the first ever networked nautical training simulation system created here at NPS. It’s creation seemed to cause much excitement by merely causing others to think about other possibilities. Such thought has led to a number of recent developments both on the surface of the ocean as well as beneath it. I hope that it has been a system which has and will continue to make a difference in the virtual simulation goals of the future here at NPS.

# X. CONCLUSIONS AND TOPICS FOR FUTURE RESEARCH

## A. CONCLUSIONS

The major objective of this research was to develop a system to support the development of basic shiphandling skills in junior surface warfare officers. These inexperienced officers are usually the primary watchstanders on ships' bridge's throughout the fleet, but in most cases, are not given the opportunity to sharpen their skills using the existing simulators either because there is no curriculum to meet their training needs and/or there is no money to dedicate to the training.

Our solution to this training deficiency was to develop a deployable version of a shiphandling simulator on a low-cost, graphics workstation that could be placed either aboard a deploying vessel or on the pier when in port. With this in mind, we developed our system on the existing off the shelf Silicon Graphics (SGI) Onyx Reality Engine workstation. The simulator was designed to operate on a single workstation with a mouse-driven graphical user interface to allow a single user ease of operation. Networking capability was also implemented to support multiship training scenarios.

For underway use, a single SGI workstation can be feasibly placed aboard a ship in an air conditioned space where junior officers could practice their shiphandling skills at their convenience. Power requirements for the workstation could be furnished by existing ship's power, provided that the appropriate electrical safeguards, such as an uninterruptable power supply (UPS), were installed.

Furthermore, the Onyx multiprocessing capability was found to be ideal in rendering the large, textured terrain database(s) required in supporting port entry, departure, and various other restricted waterway maneuvering training. During program execution, we were able to maintain frame rates of fifteen frames per second or less, which is required for smooth motion [PRAT93].

During the course of our research, several additional objectives were accomplished. The following is a very brief synopsis of those accomplishments coupled with suggestions for expanded use and application.

### 1. Implementation of Hydrodynamic Coefficients

Near the later stages of our research, we attempted to implement several of the complex hydrodynamic calculations used by [BRUT94] for our ship models. However, during initial implementation and operational testing, we experienced a significant decrease in system performance which invariably increased overall latency due to the enormous complexity of these calculations. Such a severe degradation in performance was unacceptable for two major reasons.

Firstly, because to incorporate multiprocessing techniques into the software would require much more extensive development and testing time than was available. Secondly, as shown by [BRUT94], even though multiprocessing techniques were employed in an attempt to optimize system and software performance, it was apparent that in order to maintain the highest posssible performance as prescribed [PRAT93], we would have to result to a distributed environment whereby these complex calculations can be performed in parallel on a seperate machine, thus achieving the utmost system performance. However, such an approach would violate our major design precepts of design; that being to develop a single workstation system which provides for overall system portability.

Just as significant, it is our belief that if the hydrodynamic calculations used in Brutzman's AUV model [BRUT94] can be successfully tailored for a single workstation configuration, while at the same time allowing for sustained minimal frame rates (fifteen frames per second), then the need for a distributed environment would no longer be required. Additionally, we are of the belief that this key implementation will move this system from being an introductory level training tool, to a more dynamic virtual operational exercise planning environment for afloat command staffs. However, an application such as this would certainly require a move to a more robust distributed parallel processing environment.

### 2. Incorporation of Afloat Assets into NPSNET

By adding shiphandling characteristics into the NPSNET VEHICLE class, we have made it possible for the deployable shiphandling simulator to participate in NPSNET battlefield simulations, most likely those involving amphibious landing scenarios. With the addition of shipboard weapons capability, a fleet combatant could provide naval gunfire support (NGFS) to an amphibious simulation. This would further allow for the systems additional use as a fleet operational planning tool.

Afloat staffs would for the first time ever actually have a three dimensional virtual environment possessing DIS networking capability to allow real-time feedback and insight from its participating unit commanders. This scenario alone offers several possible prospects in development of future littoral war fighting strategies.

### 3. Allowing for Future Training Scenario Development and Expansion of Ship Functionality

Our current networking capability allows for the addition of a problem control station or site. Here an operator or afloat staff could, on a separate workstation modify, add, or adjust the positions of various ships or entities participating in the virtual environment.

Additionally such features as the time of day, or change in the atmospheric environment (i.e. wind, dusk conditions, and sea state), could be initiated so as to expose operational units to a myriad of conditions which would exercise and further enhance individual war fighting capabilities. Not only would the users be subjected to numerous conditions, but they will be equally exposed to a number of shiphandling scenarios while maneuvering throughout a particular exercise scenario. Such conditions would still fulfill the systems intended purpose of presenting various rules of the road situations for individual conning officers to solve.

### 4. Make Further Use of Object-Oriented Programming Techniques to Reduce Future Development Time

Development of the deployable simulator was facilitated using existing NPSNET classes, specifically the VEHICLE class. The SHIP_VEH derived class could be further redefined as a base class for other ship classes. Two possible inherited classes of the SHIP_VEH class could be created to support different ship functionality such as that which exists between the pleasure vessels (type PLEASURE_VEH) and combatants (MILSHIP_VEH). These inherited classes would retain all of the common ship functionality of the SHIP_VEH base class with mission or type specific functions residing in the derived classes. For instance, in the case of the Pleasure Vehicle Class, sailboats which would be impacted on by atmospheric conditions such as wind, and sea state than that of a destroyer or cruiser. Another possible instance would be that of a combatant possessing self compensating ballast capability or aircraft warning light configurations which would not normally be found in pleasure vessesl types.

### 5. Utilize Three Dimensional Terrain Databases Developed from Existing Digitized Data

The San Francisco Bay terrain database used in our research was easily developed by converting available Defense Mapping Agency (DMA) digitized terrain data into MultiGen flight format. Using this method of database construction, other sea ports could be rapidly created or modified thus allowing commands to subject not only their more junior officers but equally so, all of their officers to perhaps more challenging scenarios or conditions uniquely offered by different ports frequently visited by our Naval Forces.

## B. SUGGESTIONS FOR FUTURE WORK

There are a number of potential research areas for follow-on or future work. We do not intend to list them all, however, once the system is fully understood and demonstrated to those individuals familiar with the rigors involved with shiphandling training, they themselves will derive many new and exciting ideas for future research which will invariably improve this system far beyond its current configuration.

### 1. Implementation of Head Mounted Display (HMD)

A head mounted display capability would enhance training by giving conning officers a more natural and faster means of adjusting their view of the scene. Use of the HMD would eliminate the need to manipulate control panel functions to perform the necessary head movement.

### 2. Improved Interface to Support an HMD Configuration

For single user operations, some form of interface is required to maneuver the ship or fly around the terrain while the user is wearing the HMD. The keyboard or a graphical user interface would be difficult and impractical to use in this configuration.

### 3. Voice Recognition Interface for Maneuvering

On a regular ship's bridge, conning officers maneuver their ships by means of uttering standard voice commands to persons controlling the helm (or wheel) and the engine controls. For the deployable shiphandling simulator, a voice recognition interface could aid conning officers in their use of standard voice commands by responding (repeating the commands given) and taking action (maneuvering the ship) when only the proper voice commands are given by conning officers.

### 4. Development of Multiple Terrain Databases

Additional terrain databases (e.g. San Diego Harbor, Norfolk Naval Station...etc.) could help familiarize conning officers with any port for which there is a database. By practicing entries and departures from these virtual ports, conning officers could anticipate where to look for aids to navigation and identify any problems that might be encountered prior to the real ship's entry or departure.

### 5. Development of a Command and Control Suite

On all U.S. Naval vessels, weapons are controlled from a separate compartment on the ship known as Combat Information Center (CIC). To support joint forces exercises involving deployment of weapons, a separate workstation could be used to control aiming and firing of weapons. As mentioned above, CIC's interaction with conning officers is crucial for both the safe navigation of the ship and positioning the ship to release its weapons.

### 6. Development of an Improved Hydrodynamics Model

A more accurate and dynamic hydrodynamics model could contribute to more advanced shiphandling exercises where conning officers would have to account for the effects of forces due to wind and current acting on their ship's. Other forces and features such as the drag caused by the hull moving through the water would further match the handling characteristics of the virtual ship to that of a real ship. Several additional features such as own ship mooring lines (each line force), tug forces, passing ship bow waves (pressure effects) in restricted waters (up to 15 knots), pressure and suction forces between replenishment ship and ownship (up to 15 knots), Bottom and bank effects (all water depths and sidewall configuration), closed and open piling piers for docking and getting underway, aerodynamic forces (magnitude and direction selectable), water current forces (magnitude and direction selectable), and finally sea state induced variations (sea states 0 to 6 perhaps).

# APPENDIX A: USER'S GUIDE

This appendix contains all the information necessary to load and operate the deployable shiphandling simulator.

## A. STARTING THE SIMULATOR

### 1. Using default ship

To start the deployable shiphandling simulator program using the default ship model (CG-52 located in vicinity of Golden Gate Bridge), enter the following at the unix command prompt followed by pressing the ENTER key:

**shipSimulator**

Upon sucessfull program load, a view of the ship's foredeck will be displayed in the tactical viewing area with the control panel in the lower portion of the screen (Figure A-1).

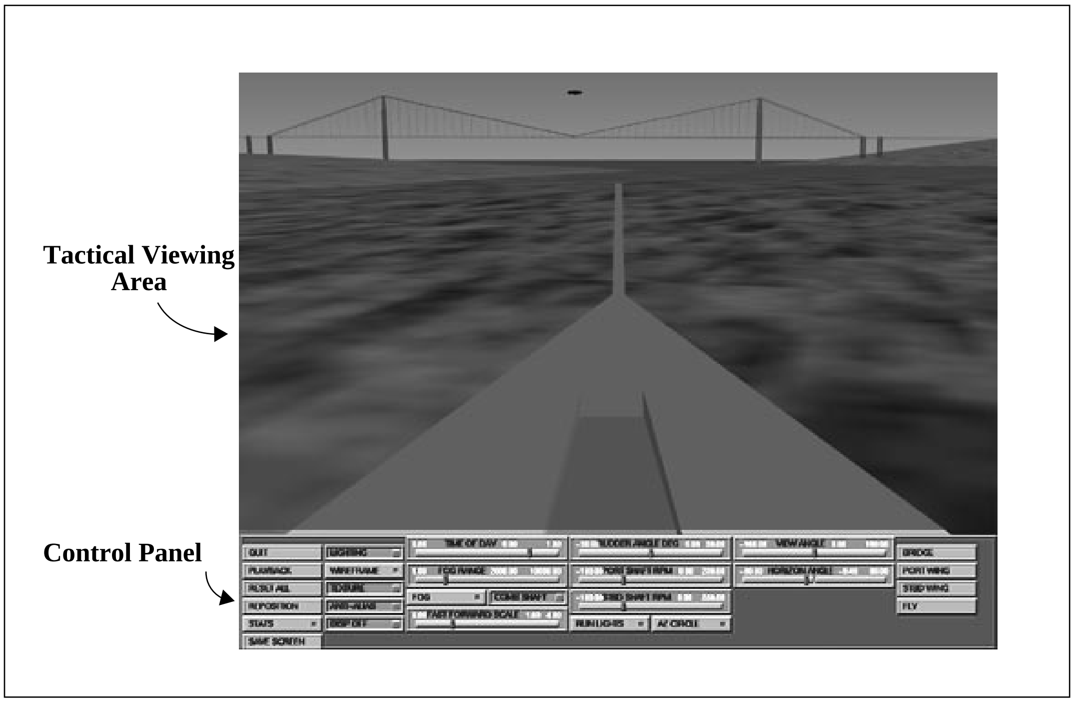


**Figure A-1: View of the Foredeck and Control Panel**

### 2. Using a ship of choice

To start the program using a ship of choice, enter the following at the UNIX command prompt:

**shipSimulator** <shiptype>

Where <shiptype > is

- **dd976** -- USS Paul Foster, located South of Alcatraz
- **cg52** -- USS Bunker Hill, located at entrance to SF Bay, near Golden Gate Bridge

Upon sucessfull program load, a view of the ship's foredeck will be displayed in the tactical viewing area with the control panel in the lower portion of the screen

## B. PROBLEM CONTROL FUNCTIONS

Problem control functions control the overall execution and administration of the program (Figure A-2). To manipulate these functions, position the mouse cursor over the desired button or toggle switch and press the left mouse button. The red indicator on the toggle buttons will illuminate when the function is activated (or turned on) and will extinguish upon deactivation.

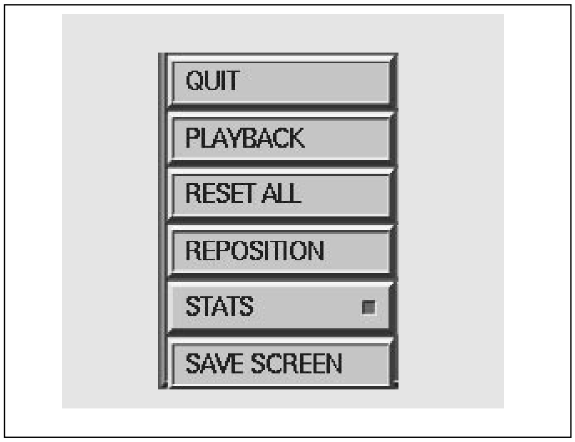


**Figure A-2: Problem Control Functions**

- **QUIT** - Exits the program and returns the user to the UNIX command prompt.

- **PLAYBACK -** Places the simulator in playback mode. When selected, the program exits the network, repositions all ships at their starting positions and then starts ships on their initial playback legs. Once executed, the real-time simulation cannot be resumed. To initiate another real time simulation, select QUIT and start the program using the procedures mentioned above.
- **RESET ALL** - Resets control panel functions back to their default settings. All associated environmental and ship maneuvering inputs will reflect the values of the default control panel settings.
- **REPOSITION -** Returns the driven ship back to its real-time simulation starting posture.
- **STATS -** Displays graphics performance at the top of the screen. Used primarily during program development.
- **SAVE SCREEN** - Takes a full screen snap shot of the tactical viewing area and control panel and saves it into an rgb formatted file. The rgb file(s) can be found in the *images* subdirectory of SHIPSIM under the name shipSim<n>.rgb where n is a sequence number from 0 to the number of times the SAVE SCREEN function was selected. This allows for multiple rgb files to be created. To prevent overwriting on subsequent program executions either rename the files or move them to a different directory.

## C. PROPULSION AND MANEUVERING CONTROLS

The propulsion and maneuvering controls (Figure A-3) are used to control the movement of the driven ship during the real-time simulation.

- **RUDDER ANGLE** - Used to change the ship’s direction of movement through the use of rudder commands. To change the course of the ship

***1. Place the mouse cursor on the vertical control bar located on the scale.***

***2. Press the left mouse button and then drag the vertical control bar in the direction of the desired turn (i.e. drag left for left turns and right for right turns).***

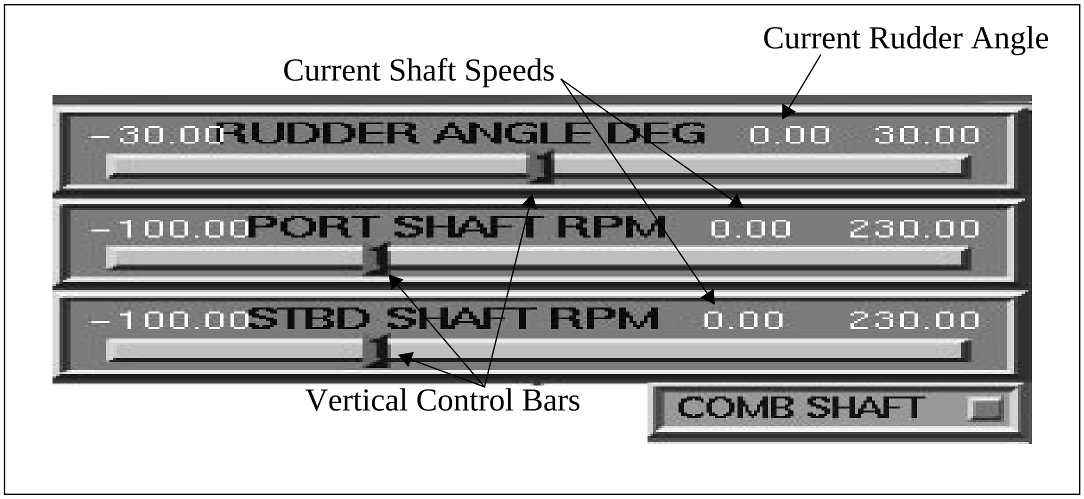


**Figure A-3: Propulsion Controls**

***The further the control bar is moved, the larger the rudder deflection and thus the faster the turn.***

***3. To stop the turn, drag the control bar back to center. The number of degrees of rudder is displayed immediately above the scale.***

- **PORT/STBD SHAFT RPM -** Used to control the speed at which the propeller shafts turn resulting in increasing or decreasing the speed of the ship. Both shafts may be controlled simultaneously or independently.

To control simultaneously (i.e. combined shaft),

***1. Ensure that the COMB SHAFT toggle button indicator is illuminated.***

***2. Place the mouse cursor on the vertical control bar located on either of the slide controls***

***3. Press the left mouse button and then drag the vertical control bar towards the maximum positive or negative shaft RPM's (negative RPM's generate reverse thrust for backwards motion).***

***4. Release the mouse when the desired shaft speeds are displayed above the slide controls.***

**To control independently**

***1. Ensure that the COMB SHAFT toggle button indicator is not illuminated.***

***2. Place the mouse cursor on the vertical control bar located of the desired SHAFT SPEED scale.***

***3. Press the left mouse button and then drag the vertical control bar towards the maximum positive or negative shaft RPM's (negative RPM's are for reverse thrust).***

***4. Release the mouse when the desired shaft speed desired is displayed above the scale of that particular shaft.***

- **COMB SHAFT -** Toggle switch used for selecting independent or combined shaft modes. Upon program start, defaults to on (combined shaft mode) with the indicator illuminated.

**To select the shaft mode**

***1.Place the mouse cursor over the COMB SHAFT toggle button.***

***2.Click the left mouse button***

## D. CHANGING VIEW LOCATIONS

Viewing locations within the scene may be selected using one of the view location push-buttons located on the right side of the control panel (Figure A-4). BRIDGE, PORT WING and STBD WING buttons will position the conning officer on the superstructure of the ship. The FLY button allows conning officers to detach themselves from the ship and fly around the terrain.

- **BRIDGE, PORT WING, STBD WING -** Positions the conning officer either on the centerline of the ship (BRIDGE), on the port bridgewing (PORT WING), or the starboard bridgewing (STBD WING). To select one of the viewing locations

***1. Place the mouse cursor over the desired view location push-button.***

***2. Press and release the left mouse button.***

- **FLY -** Flying is performed using the mouse buttons to control the speed and direction of travel. When switching between FLY and the above viewing locations, the last flying position is save. Subsequent selections of fly will return the conning officer to the previously saved position.

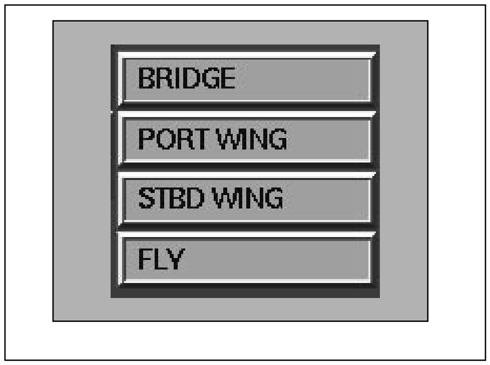


***Figure A-4: View Location Buttons***

**To fly through the scene**

***1. Place the mouse cursor over the FLY push-button.***

***2. Press and release the left mouse button.***

***3. Reposition the mouse cursor in the desired area within the tactical viewing location where to travel.***

***4. Press and hold the left mouse button to travel in a forward direction. This will have the effect of the cursor "pulling" the conning officer toward it. Leave the button pressed to accelerate.***

***5. Press and hold the right mouse button to travel in the reverse direction. This will have the effect of "pushing away" from the mouse cursor location***

## E. ADJUSTING VIEWING AND HORIZON ANGLES

When attached to one of the three shipboard viewing locations (BRIDGE, PORT WING, STBD WING), viewing angle with respect to the ship's bow and horizon angle with respect to the line-of- sight from the viewing location may be adjusted to allow "head movement". Two separate slide controls adjust these angles (Figure A-5): VIEW ANGLE and HORIZON ANGLE.

- **VIEW ANGLE -** This slide control provides side to side head movement to allow conning officers to not only look in front of them, but also to the sides and to the rear of their current position. A total of 160 degrees of viewing on either side of the ship's bow is allowed. To manipulate this function


**Figure A-5: View and Horizon Angles**

***1. Place the mouse cursor on the vertical control bar located on the VIEW ANGLE slide control***

***2. Press the left mouse button and then drag the vertical control bar towards the desired direction of viewing.***

***3. Release the mouse when the desired view angle off the bow is attained.***

- **HORIZON ANGLE** - This slide control enables up and down head movement with respect to the line-of-sight with the horizon. Positive angular values on the scale represent up head movement while negative numbers represent down head movement. To manipulate this function

***1. Place the mouse cursor on the vertical control bar located on the HORIZON ANGLE slide control***

***2. Press the left mouse button and drag the vertical control bar towards the desired horizon angle.***

***3. Release the mouse when the desired horizon angle is displayed above the slide control.***

## F. ENVIRONMENTAL EFFECTS CONTROLS

Environmental effects such as daylight intensity and fog can be changed through the use of two slide controls: TIME OF DAY and FOG RANGE (Figure A-6).

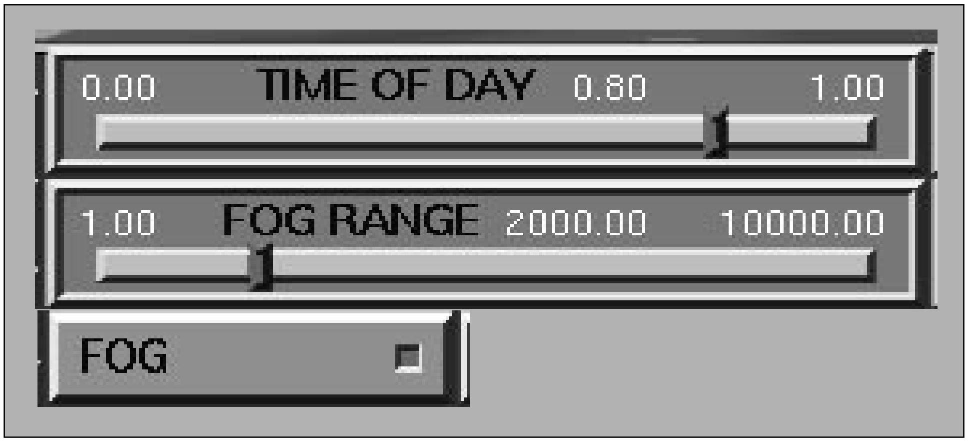


**Figure A-6: Environmental Effects Controls**

- **TIME OF DAY -** This function enables the setting of daylight intensity ranging from 0.0 (total darkness) to 1.0 (highest intensity). Upon program load, the intensity defaults to a value of 0.8. Whenever the vertical control bar is moved to the right, the daylight intensity will increase and when moved to the left, the intensity decreases. Sunrise and sunset occur at an intensity value of 0.6. When intensity falls below this threshold (moving the control bar left), all the stationary objects in the scene turn on their lights. These objects turn off their lights when the intensity goes above this threshold (moving the control bar to the right). The current daylight intensity is displayed above the slide control. To operate,

***1. Place the mouse cursor on the vertical control bar located on the TIME OF DAY slide control***

***2. Press the left mouse button and drag the vertical control bar towards the desired daylight intensity.***

***3. Release the mouse when the desired intensity is displayed above the slide control.***

• **FOG RANGE -** This function enables the setting of the range of fog (when fog is switched on) from the current position. Fog may be switched on and off using the FOG toggle button. Fog range can be adjusted from 1 meter in front of the present viewing position to 10,000 meters. The brightness of the fog varies with the daylight intensity. To display fog and adjust its range,

***1. Switch on fog by placing the mouse cursor over the FOG toggle switch and pressing the left mouse button. The indicator light on the FOG toggle button will illuminate.***

***2. Place the mouse cursor on the vertical control bar located on the FOG RANGE slide control***

***3. Press the left mouse button and drag the vertical control bar towards the desired fog range.***

***4. Release the mouse when the desired fog range is displayed above the slide control.***

## G. PLAYBACK FAST FORWARD FUNCTION

The FAST FORWARD SCALE control scale (Figure A-7) is used during playback to increase the playback speed from a default value of 1 (normal speed) to a value of 4 (fastest speed). A value of 0 pauses playback. To adjust the playback speed

***1. Place the mouse cursor on the vertical control bar located on the FAST FORWARD slide control***

***2. Press the left mouse button and drag the vertical control bar towards the playback speed (1 for normal speed, 0 to pause).***

***3. Release the mouse when the desired playback speed is displayed above the slide control.***


**Figure A-7: Fast Forward Scale**

## H. AZIMUTH CIRCLE

The AZIMUTH CIRCLE toggle button (Figure A-8) displays a set of cross-hairs in the center of the tactical viewing area to gather true bearings to objects. This function is used in conjunction with the VIEW ANGLE slide control to move the cross-hairs to the desired object. When the cross-hairs are displayed, the toggle button's indicator is illuminated. To select the azimuth circle, place the mouse cursor over the AZIMUTH CIRCLE toggle switch and press the left mouse button

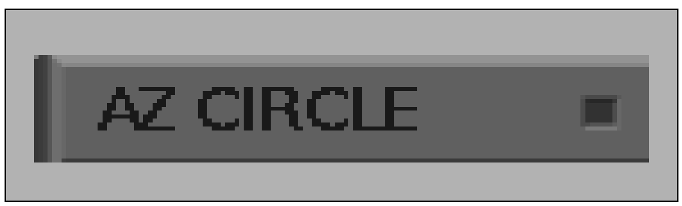


**Figure A-8: Azimuth Circle Toggle Switch**

## I. RUNNING LIGHTS

The RUNNING LIGHTS toggle switch (Figure A-9) enables the conning officer to turn the running lights of each ship in the scene on and off. When running lights are enabled, the toggle switch's indicator is illuminated. To turn on running lights, place the mouse cursor over the RUN LIGHTS toggle switch and press the left mouse button.


**Figure A-9: Running Lights Toggle Switch**

## J. GRAPHICS CONTROL SWITCHES

The graphics control switches (Figure A-10) are used for developmental purposes only and will not be included in deployable shiphandling simulators sent to the fleet. These toggle switches are activated and deactivated as those listed above

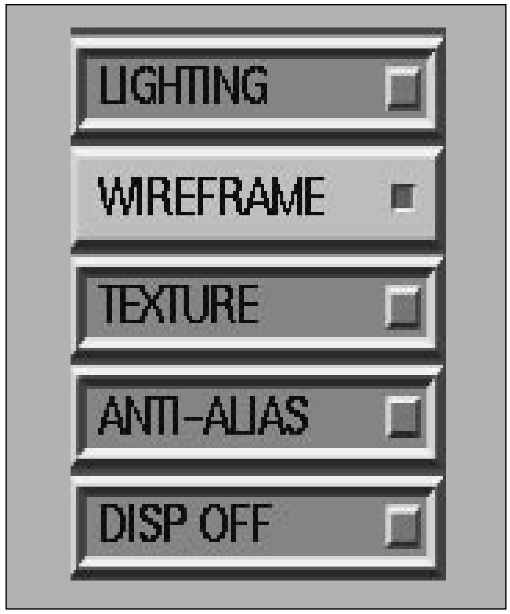


**Figure A-10: Graphics Control Switches**

- **LIGHTING** - Toggles the lighting on the geometry in the scene on and off. Defaults to on at program load.
- **WIREFRAME** - Toggles between filled polygons and wireframe to ensure proper stationary object placement. Defaults to OFF at program load.
- **TEXTURE** - Toggles the scene texture on and off. Defaults to on at program load.
- **ANTI-ALIAS** - Toggles anti-alias mode on and off. Defaults to on for those machines that have anti-aliasing hardware.
- **DISP OFF** - Turns information displayed on the tactical display (e.g., compass, azimuth circle, course, speed...etc.) on and off. Used mostly to remove information from the tactical viewing area prior to executing the SAVE SCREEN function.

## APPENDIX B: CASE HISTORIES OF COLLISION MISHAPS

This appendix contains excerpts of randomly selected case histories of collision mishaps chosen from data provided by the Navy Safety Center, Norfolk, Va. The text of each report has been transcribed verbatim as it was presented from its original manuscripts. No paraphrasing of the report, nor correction of spelling or grammar has been done.

**1.** Entering restricted waters area for first time bound for base piers. Maneuvering to regain inbound track after having opened to the right to allow inbound, faster ship to pass safely on port side, officer of the deck came too far (to the left) across center channel in his attempt to line up on channel course. Executive officer, also on the bridge, advised officer of the deck to come further right, as channel buoy number one was being approached rapidly dead ahead. Speed increased to cause a faster turn. When it was obvious that the turn would not be fast enough, backing bells were answered and ship slowed to approx one know as buoy travelled down port side. Bouy's mooring chain caught on the port stern plane surface. Ship backed off, reoriented in channel and transit continued. Subsequent investigation revealed that the buoy had been released from its moor and was reset three days later. A diver's inspection showed three propeller blades scratched and/or chipped, a maximum of one quarter inch deep, and the forward portion of the port stern plane scratched along a four foot area. No personnel were injured. The propeller was planned to be replaced during overhaul. The stern plane damage was determined to be inconsequential. **Cost: $225,000**

**2.** LCC DIW conducting mass conflag drill. FF was requested to bring firefighting water to bear on a simulated missile hit on LCC Port Side Aft. While making approach, FF collided with LCC from inadequate procedure/precaution. FF's CO received injuries to left cheek and laceration injury skin below left eye. FF's CO conning ship and failed to properly estimate drift rate of LCC. **Cost: $550,000**

**3.** AO and AR collided nearly head on, killing one crewman on AR. AR was joining formation guided by AO when they struck nearly bow to bow. Both ships sustained significant damage and resulting fires aboard. AR failed to ascertain formation information such as course, speed, etc. AO failed to ascertain AR's intentions. Both ships failed to recognize the risk of collision and take timely action and proper maneuvering action. OTC failed to ensure AR had all necessary tactical information and monitor actions of AR. **Cost: $8,260,000**

**4.** Ship conducting underway portion of INSURV Inspection. While building up for Full Power Trail, she collided with a fishing trawler under tow by another fishing trawler. Trawler sank at an approximate loss of $112,000.00. Visibility was reduced by fog. Radar Repeater on bridge was OOC. CIC Watch team was unaware of low visibility situation. Low visibility detail was not set. Radar Repeater in CIC was not operating properly. Trawlers were tracked as a contact but not reported to the bridge in a timely manner. Contact was lost in sea return at four thousand yards. OOD failed to make any recommendations to commanding officer (who was on the bridge) regarding low visibility or concerning the contact. **Cost: $112.000**

**5.** CG got underway on 2 boilers. While transiting river, experienced low water casualty in one of the steaming boilers. Commanding Officer not informed that only one boiler available. Ship approached bridge, communicated via VHF radio with bridge operator. Did not use whistle signals required by Coast Guard Regulations. Bridge started to open ship increased speed from 7 knots to 12 knots. Bridge began to malfunction and started to close. Ships speed too high to stop with only one boiler prior to hitting bridge. Anchors not used to help stop ship. Damage to bridge $30,000. **GEO LOCATION:** CONUS - Mid Atlantic Ocean - Yorktown,Va **EVOLUTION:** Transiting Restricted

Waters **HUMAN FACTORS CONTRIBUTING:** Distracted/Inattentive, Insufficient Experience/Skill/Training **COST:** $150,000

**6.** During night formation steaming at 1845 CG assigned station Starboard 170R 4000 yards for TACAN service to CV at flight quarters. 1920 after turn downwind. CG station changed to port 160R 4000. 2001 CV executes CORPEN J starboard to downwind course. 2144 CV Commanding Officer approved OOD request send signal "CORPEN J PORT 025-12". In preparation to execute at 2148 to recover aircraft at 2200. CG OOD aware of Cogs assigned duties and station. CG Commanding Officer also aware and had been informed by OOD of signals at 2001 and 2115. CG CO in wardroom watching movie. 2142 CG on course 200T/12knots making minor adjustments to maintain station. Informed bridge of maneuver and bridge acknowledged. 2148 CV execute signal starting turn to port 025T. CG made minor course changes increasing speed until 2156 then left full rudder, Captain called to bridge followed by emergency maneuvers both ships prior to collision. Relative speed 10 - 12 knots. Initial contact occurred port side CV at flight deck external to frame 78 and port side CG bridge 03 level. Ships in contact for estimated 7 seconds to 3 minutes. AS CG slid down CV side, 3 external JP-5 fuel risers ruptured, two of which charged. Fuel at rate of 1045 GPM poured onto CG with ensuing fires. CV emergency drained back fuel system within 2 minutes. CV experienced fires in sponsons portside forward. Heavy smoke and sponson contents hindered Firefighting efforts. Under control in 4 hours but reflashed up to 12. 200 SSD's used effectively. 3 of 4 CV MMR's lost power from smoke vented in from CG fire. MMR's re-manned in 30 minutes. In CG, after a few minutes the aircraft emergency diesel powering an electric fire pump became only source of firefighting water. Forward emergency gas turbine failed due to cooling problems. Some P-250's from other ships had engine failure. CG had 8 dead and 45 injured. CV had 1 dead and 2 injured. CG repair cost $210 million divided into $109 million for repair and $100 million for modification. 3200 man days lost. CV repair cost at 2.3 million. **GEO LOCATION:** OUTSIDE CONUS - Mediterranean Sea - Mediterranean **EVOLUTION:**

Formation Steaming **HUMAN FACTORS CONTRIBUTING:** Distracted/Inattentive, Insufficient Experience/Skill/Training **COST: $212.3 Million**

**7.** DLG standing in heavy fog. SSD and low visibility detail set, sounding fog signals. As ship entered inner harbor, quality of fixes decreased. 10 minutes prior to collision, CIC advised CONN of a ship anchored 4000 yards ahead on the proposed track. Bridge phone talker later stated he reported information to bridge personnel, received acknowledgment, but failed to ascertain by whom. Due to construction in progress on a bridge-tunnel. Temporary buoys marked a channel slightly to the right. The temporary channel and DLG's proposed track went through anchorage N8A "west of the bridge tunnel zone". DLG crossed bridge tunnel 4 minutes prior to collision making turns for 6 knots and experiencing a 1.6 knot westerly set due to a flooding tide. At ranges of 1200 and 800 yards. CIC again warned of the anchored ship on track and at 600 yards and recommended "all stop". CO who had not heard earlier CIC reports, upon hearing recommendation for "all stop" took the CONN. At this time anchored ship sighted. In minutes before collision, CO attempted pass bow of anchored foreign merchantman anchor chain. Further maneuvers stopped to avoid damage to sonar dome or propellers. Tide set DLG onto the merchantman bow. DLG took collision on IC mast and antenna system and hull area, boat and davits, electronic mast and antenna system and internal machinery. Later investigators revealed that merchantman had not been sounding for signals nor displayed required lights. She was anchored in a proscribed area which had been designated by the USCG Captain of the port as required by bridge-tunnel work. **GEO LOCATION:** CONUS - Mid Atlantic Ocean - Hampton Roads, Va **EVOLUTION:** Transiting Restricted Waters **HUMAN FACTORS CONTRIBUTING:** Distracted/Inattentive, Failed to take Corrective Action (Time Was Available) **COST:** $827,197

**8.** Both ships conducting underway replenishment practice. Ship One was guide and Ship Two making approach to starboard side of ship one. With about 160 foot separation OOD ordered heading of 048 to close separation. In the following seconds ship two swung rapidly to port to heading of about 030 and raked its bow down starboard side ship one causing damage to lift lines and helo safety nets. Investigation determined that helmsman had been using excess rudder and spinning helm. Also had to step away from helm and take eyes off compass repeater and rudder angle indicator to receive orders through voice tube and make repeat backs. Three minutes prior to collision there were about 32 exchanges between OOD and helmsman. When ship started to swing left helmsman thought he had lost rudder control, not realizing that he had applied 25 degrees of left rudder. He sounded steering alarm and aft steering took over compounding the error. Officer helm monitor was unable to recognize developing situation because his view was blocked by movements of helmsman. **GEO LOCATION:** CONUS - Caribbean Sea **EVOLUTION:** Replenishment At Sea **HUMAN FACTORS CONTRIBUTING:** Personnel Error on Ship Two, Insufficient Experience/Skill/Training **COST:** $258,000

**9.** PG vessel operating in Northern End of the Windward Passage picked up a radar contact bearing 163T, range 10 nautical miles. Coact had a constant bearing and decreasing range. PG's course was 175T, speed 12.5 knots. Commanding Officer informed of contact and ordered course and speed maintained. CO was again called when range to contact was four miles bearing 163T. CO was also informed at this time that call signs had been exchanged via flashing light. When range was 5500 yards, CO called and immediately went to bridge. Masthead and green running light were clearly visible and a considerable separation between masthead and range lights. There was no doubt that PG was the privileged vessel and thus required to hold course ad speed. When range closed t 2500 yards, PG sounded five short blasts with no reply from other vessel. At 0321 range 700 - 1000 yards, PG put her rudder over right full and rang up max speed. At 0322 PG was struck on the port side by foreign registry who immediately backed clear after the collision. PG became dead in the water after collision with a gash 10 feet wide, 6 feet inboard with 2 feet penetration below the water line. Fires raged and burned for 30 minutes before being extinguished. Several reflashes occurred and firefighting hampered by loss of all AFFF foam and CO2 was a result of the collision. Fires were fought entirely with water. Dewatering was delayed five hours due to nonavailability of a pump. Progressive flooding occurred in gas turbine machinery room through rip in power turbine coupling assembly. DD came to the scene from 12 miles at 0408. DD transferred men and equipment to PG. At 0658R, PG was taken in tow and at 1041 ATF took PG in tow arriving in port at 2100 hours. Damage to fault ship of foreign registry was not included in this report. **GEO LOCATION:** Outside CONUS - Caribbean Sea **EVOLUTION:** Independent Steaming **HUMAN FACTORS C**ONTRIBUTING: Fault lies with Foreign Registry COST: $600,000

**10.** DD was proceeding Southwest in a channel about 175 yards wide. DD was making 18 knots and overtaking a merchant vessel. Permission to pass was requested and received over FM ship-to-ship radio. DD commenced passing maneuver with a 3 knot speed advantage and estimated 200 foot lateral separation. As the bow of the DD came abreast of the quarter of the merchant vessel, DD veered sharply to the right making contact worth merchant port quarter. Last minute backing and left rudder was ineffective. DD suffered extensive damage to hull structure in the area of the starboard anchor. Damage to merchant was not determined at the time. Merchant returned to port. 0 hours. Damage to fault ship of foreign registry was not included in this report. **GEO LOCATION:** CONUS - Mid-Atlantic Ocean - Tampa, Fl **EVOLUTION:** Independent Steaming **HUMAN FACTORS CONTRIBUTING:** Inability to recognize hazardous situation, Insufficient experience/skill/training. **COST:** $117,000

**11.** On 19 January LKA at anchorage in 31 feet of water. Sand bottom with starboard anchor (30 fathoms at waters edge). Engine room had 1boiler on line for auxiliary purposes and on 4 hour standby. Prior to 0100 21 January LKA began to drag anchor. When ship 80 yards from bridge, port anchor dropped but ship continued to drag anchor. At 0106 LKA struck “Trestle” of bridge stern first. Bridge collapsed, LKA went thru gap and collided bow first with other side of bridge. AT 0321 engine room did not report ready to answer all bells until 1341. Cost to the bridge $2,000,000. **GEO LOCATION:** CONUS - Mid Atlantic Ocean - Chesapeake Bay **EVOLUTION:** Anchored **HUMAN FACTORS CONTRIBUTING:** Supervisor Error (CO) lack of training of the midwatch, lack of sufficient practical experience of the midwatch, failed to recognize hazard on part of the OOD and Navigator, operator error on the part of the OOD, GM of watch and navigator, improper navigational fixes **COST:** $104,045

# APPENDIX C: USABILITY INSPECTION SURVEY INSTRUMENT

This appendix contains a complete copy of the Usability System Evaluation Survey Instrument used in conducting a post-evaluation of the Deployable Shiphandling Training Simulator. The results of the survey can be found in Chapter X of this thesis document.

# Deployable Shiphandling Training

# Simulator System Evaluation

Written and Developed

by

LCDR J. A. Nobles

# Deployable Shiphandling Training Simulator System Evaluation

To The Participant:

Before getting started, let us extend our sincere gratitude to you for taking time out of your busy schedule to participate in this usablity inspection and iterative testing evaluation. Our primary goal is to determine what role and to what degree this system can play in aiding in the training and development of those shiphandling skills so critically important to the successful and safe operation of one of our nation's most crucial defense assets, its surface ships and submarines, by its most junior Surface Warfare and Submarine Officers.

Currently such training is only available to more senior officers beginning at the department head stage of their career. Thus, for many of these juniors, exposure to this form of training may not take place until the six - eight year point in their careers. Meanwhile, any training that these junior officers may be fortunate enough to receive, occurs in spite of the myriad of inter-fleet operational exercises and during what has increasingly become limited underway periods.

Before the evaluation period begins, you will receive a brief overview of the system and this evaluation instrument. Once again, our goal is to determine the effectiveness of this deployable version of the full-scale simulators currently being used to train more senior officers. It is our belief that by making use of such a system, that the responsibility to train junior officers can be placed squarely on the shoulders of the individual commands. Unlike in the past, Commanding Officers will have a truly dynamic tool designed to further assist them in not only the training of these officers, but even moreso, they can evaluate the effectiveness of targeted training for each individual officer. This further allows them to faciliate corrective training in those areas where either the overall program or the individual program fails to meet minimum criteria.

An additional benefit of this system is that commands can develop their own tailored "in-house" training programs which will allow specific emphasis into those areas which they feel are most important to the overall development of the officers assigned to their comand.

Throughout this evaluation period, you will be asked to examine several key areas which are critical to both the design and further development of this computer application software. You will be asked to perform specific tasks directly related to the required knowledge and skill levels of a naval shiphandler. We believe this to be the best means of determining what changes can best be made to improve our system.

In each area, you will find a number of questions specifically related to these tasks as well as sufficient space to comment on any items not covered by the evaluation instrument. We encourage you to jot down your comments as you progress through the evaluation, rather than waiting until its conclusion.

Several of the tasks that you will be asked to perform are as follows:

- Mooring to a pier.
- Getting underway from a pier.
- Transiting a restricted waterway (i.e. entering and leaving port)
- Manuevering within a restricted waterway
- Formation Steaming

The allotted time for this evaluation period will be approximately 1.5 to 2.0 hours. However, more time can be allotted if needed. Feel free to ask for assistance at any time during the evaluation period. Upon conclusion of the test, we ask (time permitting) that you review your evaluation instrument with us to make sure that all comments are clearly understood. We will be as brief as possible so as not to detain you unnecessarily.

Once again thank you for taking the time to help us in the evaluation of our system.

Please read each of the following statements and sign below upon completion.

- I have freely volunteered to participate in this experiment.
- I have been informed in advance what my task(s) will be and what procedures will be followed.
- I have been given the opportunity to ask questions, and have had my questions answered to my satisfaction.
- I am aware that I have the right to withdraw consent and to discontinue participation at any time, without prejudice to my future assignment or treatment.
- My signature below may be taken as affirmation of all the above statements, it was given prior to my participation in this study.

# Simulator System Evaluation

Name :____________________ Rank: _____ Date: _______ 95

email address: ________________________ Phone: __________ (w) ___________ (h)

This evaluation instrument will enable us designers and developers of this system to get the best possible feedback from you the experienced user. We feel that your past experience as a shiphandler, offers us a unique opportunity to gain important feedback on ways in which we might further enhance this system. You will be asked to evaluate several areas as objectively as possible. In most cases we've provided sufficient space to allow you to make additional comments regarding each area. However, if you run out of space, feel free to make your comments on the reverse side of the page(s) as you progress.

## 1.0 Computer Experience

In this area, we want to get a feel for your level of basic or general knowledge of computer systems.

1. Please list several of the different types of computer systems, including mainframes and personal computers, you have worked with (e.g. Macintosh, DEC, VAX, IBM PC, SGI, Sun, Solbourne)?

(a) (d)

(b) (e)

(c) (f)

2. Of the following devices, software, and systems, check those that you have personally used and are most familiar with:

___keyboard ___text editor
___color monitor ___numeric key pad
___word processor ___time shared system
___mouse ___word processor
___workstation ___light pen
___file manager ___personal computer
___touch screen ___electronic mail
___floppy drive ___track ball
___computer games ___compact disk drive

3. Please check the word or phrase which best describes your level of comfort when using mouse driven software?

___not at all comfortable
___fairly comfortable
___comfortable

___reasonably comfortable
___very comfortable
___expert

4. What basic operating system would you say you are most familiar with?

| | | |
|---|---|---|
| ___Unix | ___OS/2 | ___Windows |
| ___Lynx | ___DOS | ___ Apple |
| ___Other | ___MacIntosh | |

5. For each of the following terms, circle the number which indicates the degree to which you feel most comfortable with each of the following terms:

| | not familiar | | | very familiar |
|---|---|---|---|---|
| a. Artificial Reality | 1 | 2 | 3 | 4 |
| b. Virtual Reality | 1 | 2 | 3 | 4 |
| c. GUI | 1 | 2 | 3 | 4 |
| d. Direct Manipulation | 1 | 2 | 3 | 4 |
| e. Virtual Environment | 1 | 2 | 3 | 4 |
| f. Synthetic Environment1 | 1 | 2 | 3 | 4 |
| g. Virtual Worlds | 1 | 2 | 3 | 4 |
| h. Visual Simulation | 1 | 2 | 3 | 4 |
| i. Immersion | 1 | 2 | 3 | 4 |
| j. Networked Interactions | 1 | 2 | 3 | 4 |

5. How many computer software games do you personally own (i.e. not purchased for use by other family members)? _____

6. Of these, list those games which are related to warfare (i.e. Harpoon, Gato, etc.).

| | |
|---|---|
| (a) | (b) |
| (c) | (d) |
| (e) | (f) |

7. Check the answer which best describes you:

a. When I am exposed to a new software package, I tend to skip the instructions and just jump right in and experiment as to how to operate it. ___T ___F

b. I believe that today's computer systems and software are designed so well, that they are virtually intuitive when it comes to operating them? ___T ___F

c. I don't believe that computer assisted instruction holds much promise as an effective means of training military personnel in today's highly automated combat environment. ___T ___F

| | | |
|---|---|---|
| d. Virtual Reality, Artificial Reality and all of those “fifty-cent” computer terms being tossed around in today's computer market, is nothing more than a lot of smoke and mirrors used to mark the next generation of video entertainment systems. | ___T | ___F |

## 2.0 Shiphandling Experience

1. How many years of shiphandling experience have you had during your career as a Surface Warfare or Submarine Officer?

___1 - 2 years ___2 - 4 years ___> 4 years

2. During your career, how many different types (or classes) of ships have you had an opportunity to drive?

___1 ___2
___3 ___> than 3

3. What specific ship types have you had an opportunity to drive (i.e. conn)? (DD, SSBN, CG, etc.)

(a) ________ (b) ________
(c) ________ (d) ________

4. From the above listed ship types how many did you obtain qualifications as Officer of the Deck (OOD)? _____

5. Please list the particular ship type (starting with the most recent) and the approximate number of months it took you to complete the required prerequisites for obtaining final OOD qualifications?

| Ship Type | Months to Qualify |
|---|---|
| (a) _______________ | ____ |
| (b) _______________ | ____ |
| (c) _______________ | ____ |
| (d) _______________ | ____ |
| (e) _______________ | ____ |

6. While assigned in your last (or most recent) afloat command, what percentage of the time would you say you were assigned as either OOD or Conning Officer during the following or similiar underway evolutions?

| Ship Type | Evolution | OOD Pct. | Conn Pct. |
|---|---|---|---|
| (ex.) DD-963 | Sea & Anchor | 50 | 25 |
| | Unrep | 100 | 20 |
| (a) ______________ | Sea & Anchor | ___ | ___ |
| | UNREP | ___ | ___ |
| | Flight Qtrs | ___ | ___ |
| | SAR Mission | ___ | ___ |
| | GQ | ___ | ___ |
| | **Other(s)** | | |
| | __________ | ___ | ___ |
| | __________ | ___ | ___ |

7. In any of the assigned ship types listed above, were you ever formally assigned as OOD/Conn on the ship's Watch, Quarter, and Station Bill (WQS)? If so, which one(s) (ship type):

| Ship Type | Assigned to: |
|---|---|
| (a) ________ | ____________________ |
| (b) ________ | ____________________ |
| (c) ________ | ____________________ |
| (d) ________ | ____________________ |

8. Throughout your Naval career, have you received any formal training through any established shiphandling training simulation programs?___ Yes ___No

9. How would you rate the shiphandling training programs on each of the ship types you've previously been assigned to?

1 - Did Not Exist 4 - Average
2 - Poor 5 - Good
3 - Fair 6 - Above Average

| Ship Type | Rating |
|---|---|
| (a) _________ | ______ |
| (b) _________ | ______ |
| (c) _________ | ______ |
| (d) _________ | ______ |

9. To what degree do you feel the Commanding Officer(s) of the vessels you served in tended to foster a healthy and positive training environment for junior officers to learn and develop their shiphandling skills?

Comment:
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

10. Briefly describe the Commanding Officer who you felt demonstrated the **worst** shiphandling skills of the vessels you've served in? (What traits did he/she lack which created a barrier to your learning from him/her. (A name is not necessary!)

Comment:
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

11. Briefly describe the Commanding Officer who you felt demonstrated the **best** shiphandling skills of the vessels you've served in? What traits did he/she possess which encouraged your desire to from him/her. (A name is not necessary!)

Comment:
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

12. What additional training or tools do you feel the Navy could have provided you with to enhance your abilityto learn and understand proper shiphandling techniques?

Comment:

## 3.0 Task Performance (To be filled in after the completion of the evaluation)

During this portion of the evaluation period, you will be asked to perform several task(s) normally required as prerequisites for qualifying as an Officer of the Deck (OOD) Underway. You will receive this portion of the evaluation separately and upon completion, return to this document to complete the post-evaluation portion of the survey.

We ask that you attempt to perform each of the assigned tasks in accordance with the scripted task scenario and that you do so to the best of your ability. When prompted, please record the required information when asked.

Below is a list of those tasks you will be required to perform. Please feel free at any time to ask questions regarding the specifics of their performance.

Required Tasks:

(a) Determine bearing to an object(s).

(b) Determine course to steer.

(c) Getting underway from anchorage.

(d) Moor to a buoy.

(e) Determine target angle of a contact during daylight hours.

(f) Determine bearing drift of a surface contact and its significance to risk of collision.

(g) Get your ship underway from a pier.

(h) Bring your ship alongside a pier.

(i) Transit a restricted waterway during reduced visibility (Fog).

(j) Transit a restricted waterway during night time.

(k) Perform a SAR for a downed aircraft.

(l) Rendezvous with another vessel at-sea.

**NOTE:** You will be alotted approximately 5 minutes to become familiar with the graphical user interface (GUI) displayed on at your workstation.

## 3.1 Overall User Reactions

Now that you've completed the scripted evaluation scenario, please answer the following questions by circling the numbers which most appropriately reflect your impressions about its use.
**Not Applicable = NA.** Remember additional comments can be made on the reverse side if needed.

| | | | | | |
|---|---|---|---|---|---|
| 1. Overall reactions to the system: | Terrible | | | Wonderful | |
| | 1 | 2 | 3 | 4 | NA |
| 2. | Frustrating | | | Satisfying | |
| | 1 | 2 | 3 | 4 | NA |
| 3. | Dull | | | Stimulating | |
| | 1 | 2 | 3 | 4 | NA |
| 4. | Difficult | | | Easy | |
| | 1 | 2 | 3 | 4 | NA |
| 5. | Inadequate Power | | | Adequate Power | |
| | 1 | 2 | 3 | 4 | NA |
| 6. | Rigid | | | Flexible | |
| | 1 | 2 | 3 | 4 | NA |

Additional Comments:

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

## 3.2 Display Screen

| | | | | | |
|---|---|---|---|---|---|
| 1. Characters on the screen. | Hard to read | | | Easy to read | |
| | 1 | 2 | 3 | 4 | NA |
| 2. Arrangement of control functions. | Poor Placement | | | Good logical placement | |
| | 1 | 2 | 3 | 4 | NA |
| 3. Did control layout help or hinder tasks performance? | Strong hinderance | | | Not at all a Hinderance | |
| | 1 | 2 | 3 | 4 | NA |
| 4. Screen space was | Too Crowded | | | Sufficient Space | |
| | 1 | 2 | 3 | 4 | NA |

| | | | | | |
|---|---|---|---|---|---|
| 5. Control Widgets were | Confusing | | | Clear | |
| | 1 | 2 | 3 | 4 | NA |
| 6. Display of control feedback | Tough to read | | | Located in Good location | |
| | 1 | 2 | 3 | 4 | NA |
| 7. Labelling of Icons/Widgets | | | | | |
| (a) Coloring | Poor contrast | | | Correct Contrast | |
| | 1 | 2 | 3 | 4 | NA |
| (b) Representation | Not at all | | | Good Enoough | |
| of Actual Equipment | 1 | 2 | 3 | 4 | NA |
| 8. Selected Icons were clearly | Hard to distinguish | | | Easy to distinguish | |
| | 1 | 2 | 3 | 4 | NA |
| 9. Arragement of information on | Illogical | | | Logical | |
| screen. | 1 | 2 | 3 | 4 | NA |
| 10. Character Shapes(fonts) | Barely legible | | | Very legible | |
| | 1 | 2 | 3 | 4 | NA |
| 11. Beginning, middle and end of | Confusing | | | Clearly marked | |
| tasks. | 1 | 2 | 3 | 4 | NA |

## 3.3 Terminology and System Information

1. Use of terms throughout the system

| | | | | | |
|---|---|---|---|---|---|
| Impossible | | | | Easy | |
| 1 | 2 | 3 | 4 | 5 | NA |

2. Terms on the screen

| | | | | | |
|---|---|---|---|---|---|
| Ambiguous | | | | Precise | |
| 1 | 2 | 3 | 4 | 5 | NA |

3. Messages which appear on the screen

| | | | | | |
|---|---|---|---|---|---|
| Inconsistent | | | | Consistent | |
| 1 | 2 | 3 | 4 | 5 | NA |

4. Position of instructions on the screen.

| | | | | | |
|---|---|---|---|---|---|
| Inconsistent | | | | Consistent | |
| 1 | 2 | 3 | 4 | 5 | NA |

5. Instructions for commands or choices were

| | | | | | |
|---|---|---|---|---|---|
| Confusing | | | | Clear | |
| 1 | 2 | 3 | 4 | 5 | NA |

6. Does the system keep you informed about what it is doing?

| | | | | | |
|---|---|---|---|---|---|
| Never | | | | Always | |
| 1 | 2 | 3 | 4 | 5 | NA |

7. Performing an operation leads to a predictable result.

| | | | | | |
|---|---|---|---|---|---|
| Never | | | | Always | |
| 1 | 2 | 3 | 4 | 5 | N |

## 3.4 Learning

1. Learning to operate the system

| | | | | | |
|---|---|---|---|---|---|
| Difficult | | | | Easy | |
| 1 | 2 | 3 | 4 | 5 | NA |

2. Getting Started

| | | | | | |
|---|---|---|---|---|---|
| Difficult | | | | Easy | |
| 1 | 2 | 3 | 4 | 5 | NA |

3. Learning advanced features

| | | | | | |
|---|---|---|---|---|---|
| Difficult | | | | Easy | |
| 1 | 2 | 3 | 4 | 5 | NA |

4. Time to learn to use the system

| | | | | | |
|---|---|---|---|---|---|
| Slow | | | | Fast | |
| 1 | 2 | 3 | 4 | 5 | NA |

5. Exploration of features by trial and error.

| | | | | | |
|---|---|---|---|---|---|
| Discouraging | | | | Encouraging | |
| 1 | 2 | 3 | 4 | 5 | NA |

6. Exploration of features

| | | | | | |
|---|---|---|---|---|---|
| Risky | | | | Safe | |
| 1 | 2 | 3 | 4 | 5 | NA |

7. Discovering new features

| | | | | | |
|---|---|---|---|---|---|
| Difficult | | | | Easy | |
| 1 | 2 | 3 | 4 | 5 | NA |

8. Remembering names and use of commands.

| | | | | | |
|---|---|---|---|---|---|
| Difficult | | | | Easy | |
| 1 | 2 | 3 | 4 | 5 | NA |

9. Remembering specific rules about entering commands.

| | | | | | |
|---|---|---|---|---|---|
| Difficult | | | | Easy | |
| 1 | 2 | 3 | 4 | 5 | NA |

10. Can tasks be performed in a straight-forward manner?

| | | | | | |
|---|---|---|---|---|---|
| Never | | | | Always | |
| 1 | 2 | 3 | 4 | 5 | NA |

## 3.5 System Capabilities

1. System provides an intuitive visual layout.

| Not at all | | | | Very much so |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

2. Current design minimizes the user's memory load.

| Falls far short | | | | Well accomplished |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

3. Provides minimum functionality required to perform assigned tasks.

| Less than | | | | Everything needed is there |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

4. Possesses good help features

| Not at all | | | | Very much so |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

5. System speed

| Too slow | | | | Fast enough |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

6. Response time for most operations

| Too slow | | | | Fast enough |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

7. Rate information is displayed

| Too slow | | | | Fast enough |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

8. How reliable is the system?

| Too slow | | | | Fast enough |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

9. Operations are

| Undependable | | | | Dependable |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

10. System failures occur

| Frequently | | | | Seldom |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

11. System warns the user about potential problems.

| Never | | | | Always |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

12. Are the needs of both experienced and inexperienced users taken into considerations?

| Never | | | | Always |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 NA |

13. Novices can accomplish tasks knowing only a few commands

| | | | | | |
|---|---|---|---|---|---|
| With difficulty | | | | Easily | |
| 1 | 2 | 3 | 4 | 5 | NA |

14. Experts can-use features/shortcuts

| | | | | | |
|---|---|---|---|---|---|
| With difficulty | | | | Easily | |
| 1 | 2 | 3 | 4 | 5 | NA |

## 4.0 Additional Comments

In order to enhance the effectiveness of this system's capabilityof becoming a viable and effective training tool, we would like your comments on the following additional topics or areas.

(a) Graphical User Interface
(b) Conformity to specific standards (i.e. Does the system afford you the use of all or some of the standard commands required to perform assigned task(s)?
(c) Conformity to common UI conventions
(d) Aesthetics
(e) Expected functionality
(f) Usefulness
(g) Range and Field of Depth
(h) Casualty Control Drill Training
(i) Head Mounted Display
(j) Water Depth
(k) Sound Effects
(l) Communications
(m) Additional Shipping (i.e. Increased traffic density)

Comments:

# Simulator Exercises

## 5.0 Exercise Design

This shiphandling simulator exercise is designed to provide training and practice in four general categories of ship manuevers:

a. Shiphandling in restricted waters

b. Shiphandling in open sea

c. Shiphandling alongside

d. Shiphandling in anchoring and mooring

You will participate in a minimum of 4 - 8 shiphandling exercises as OOD/conning officer. The exercises are not only designed around the role as conning officer (manuevering decision maker), but also as the OOD (as the bridge team supervisor). When you are in either frame of mind, you should pay particular attention to the description of the exercise, its initial conditions and training objectives.

### 5.1 Exercise Descriptions

The following are general descriptions of the exercise types. Any specific exercise will contain variations on its objectives. As conning officer, you will want as many details as possible about the manuever you have been asked to do; therefore, exercise information will be provided prior to commencement.

Because this is a networked virtual environment, you will be assigned to command either of the two ships featured in the system -- the DD-976 or the CG-47. Both vessels can be operated completly autonomous of one another. However, at some particular point in the evaluation, you will required to operate as a team (jointly) while participating in specific tasks. Remember, that our goal is to evaluate the realism and functionality of the system. At the same time, we want you to enjoy the experience of revisiting your days when station on one of the Navy’s finest seagoing platforms.

## 5.2 For DD-976 Platform

### 5.2.1 SHIPHANDLING IN RESTRICTED WATERS (Mooring to a Pier)

You are standing in the restricted waters of San Francisco Bay, approximately 300 yds South of Alcatraz Island (home of the famous “Rock” -- Alcatraz Federal Prison) bearing $340.5^0$ - $040.5^0$ T off your starboard beam. Immediately off your port beam is the Fisherman’s Wharf area approximately 700 yds, bearing $122^0$ - $210^0$T. Your current heading is $270^0$T and you are lying-to, with no way on.

Your first task calls for getting underway and piloting your ship to conform to the restricted waterway completely around Alcatraz Island (encircling the island). Upon returning to your approximate original position, manuever your ship to any of the piers of your choice located along the waterway. (Due to the collision detection feature being on, you will only be able to approach the pier to within approximately 20 feet). Once you are satified with your position, you may proceed to the next task. **Remember to make mental and written notes regarding each task as you progress**.

Comments:
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

### 5.2.2 SHIPHANDLING IN RESTRICTED WATERS (Getting Underway from a Pier)

Now that you have successfully moored your vessel alongside a pier (of your choice), prepare to get underway by clearing the mooring location and any harbor obstructions or traffic, then bring your ship fair for sortie in the harbor or departure channel.

It is the objective of this exercise to refamiliarize you with preparations for getting underway. You will practice the use of various engine combinations, the rudder, shooting bearings to stationary objects, and your basic instinct for safely handling your vessel as you sortie seaward through the restricted waterway.

The recommended course for exiting port is (for Leg1) $270^0$T. Upon reaching a bearing of $229^0$ - $235^0$T on the first black buoy off your port bow, come left to course $252^0$T. You will remain on this course for a while, which will place you on a course to the Golden Gate Bridge.

As you approach the second black buoy off your port bow, you will commence your next course change (for Leg2) to $243^0$ - $246^0$T. The turn bearing for the second black buoy should be $207^0$ - $212^0$T. Dead ahead you should see two platform buoy towers off the port and starboard bows respectively at approximately 10,000 - 14,000 yds. Also you will notice several navigation aides off your port and starboard bows near land (green and red buoys) indicating the location of shoal water. After clearing the bridge, you shall increase speed to either a FULL (20 knots) or FLANK BELL (30 knots).

Comments:

### 5.2.3 Transiting A Restricted Waterway (Outbound)

Upon clearing the Golden Gate Bridge, adjust your course to 248 - $252^0$T (for Leg3). This will take you directly between the two buoy platforms leaving you with approximately 300 yards of good water off both the port and starboard beams. You may increase your transit speed to 30 knots if desired. This will significantly reduce your outbound transit time. The transit will take approximately 5 - 10 minutes.

During your transit toward the platform buoys, practice your use of the Azimuth Circle feature by taking bearings to various landmarks and navigational aides. You may want to experiment with any of the other controls featured on the panel. Please provide feedback on these components and any others available in the comments space provided below. **DO NOT MANIPULATE THE FOLLOWING CONTROL WIDGETS:** (1) Quit, (2) Playback, (3) Reset All, (4) Reposition, and (5) Save Screen.

Comments:

### 5.2.4 Transiting a Traffic Separation Scheme (Outbound)

As you reach the two buoy platforms, your fourth and final course (for Leg4) will take you through a 2,000 yard wide traffic separation scheme. You should have noticed several its buoys as you were approaching the two seaward platform buoys.

While traversing the channel, you will notice both red - black band bouys to port and green - black band bouys to starboard. Your turn bearings (to the port platform) $220^0$ - $225^0$T and (to the starboard platform) $278^0$ - $285^0$T. This new course should take you directly down the traffic separation scheme. Your final course should be $232^0$ - $234^0$T. Shortly after steadying up on this new course, you should notice another platform bouy dead ahead bearing $233^0$T. This is S.F. Bay Buoy-1, the last platform bouy you will see when leaving port and the first upon your return to port.

While maintaining this course, you are encouraged to experiment with the various control panel features and comment on this portion of the exercise.

Comments:

### 5.2.5 SHIPHANDLING IN AN OPEN OCEAN (Performing Basic Shiphandling Manuevers)

Now that you've exited the traffic separation scheme and are approaching S.F. Bay Buoy-1, you should notice off the port beam another group of buoys located just beyond the current buoy channel (alternating white and blue buoys). Upon clearing the last group of buoys of the separation scheme, come to a southerly course which will cause you to enter this practice manuevering range of sorts. It is here where you will spend the next 5 - 10 minutes practicing a number of shiphandling tasks. For navigational purposes, there is also a red and yellow buoy platform located further seaward of this buoy scheme (or practice buoy range). You will be asked to moor (marry up) to this buoy later in the exercise). **At this time, feel free to manuever the ship as you like. Be mindful, that another vessel will be transiting outbound the main channel headed to rendezvous with you in this general area.**

After clearing the main separation scheme, commence the following manuevers.

(1). With one of the buoys serving as a marker, practice the following man overboard manuevers:

a. Williamson Turn    b. Figure Eight

c. Race Track    d. A manuever of your choice

(2). Imagine a temporary steering casualty, attempt to manuever your vessel through the alternating white and blue buoys (by way of an S-curve) passing each one as you traverse them.

(3). Manuever to locate the three yellow seaward traffic buoys located near the S.F. Bay Buoy-1.

(4). Manuever your ship to marry to the White and Red colored platform buoy.

Please provide feedback on such things as the ship's handling features and characteristics. Did you get a good feel for basic shiphandling procedures? How did the ship respond both with and without the use of the rudder?

Comments:

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

## 5.3 OPERATING IN COMPANY WITH ANOTHER VESSEL

**Note: You may or may not have the opportunity to work with the other vessel. In the event that you do not, proceed with the exercise as a single SAR unit.**

This portion of the exercise will focus on basic station keeping and formation steaming with other ships in company. There are a number of things to consider while operating in this particular mode. Here are but a few of the items or factors to consider:

(1) The importance of the wake of accompanying ships.

(2) Set and Drift

(3) Stern view of trailing vessels

As you progress, see if you can think of other items which would enhance the overall fidelity and realism of the system for the intended user(s).

### 5.3.1 Conduct A Search and Rescue Operation

By the time you complete the manuevering in an open ocean waterway exercise, the second of the two vessels (CG-52) featured with system should have made its way to your position (near SF Bay Buoy-1). Upon sighting it, you are to rendezvous with it taking station astern approximately 500 to 1,000 yards. This vessel will become the OTC as you proceed through the next portion of the exercise. The CG should commence a reciprocal course change which will cause both vessels to transit back up the traffic separation scheme after rounding SF Bay Buoy-1.

When directed, proceed to take station on the Guide in the formation specified (i.e. astern, on the port/starboard beam, etc.). You will be commence a Search and Rescue operation during this next phase of the exercise.

Immediately after clearing the traffic scheme adjust your time of day control to 0.50. This will reduce the range of visibility and simulate night time operations. You will be operating in this environment for the remainder of the exercise.

The both ships will simulate receiving emergency S.O.S messages from an aircraft in distress. Its approximate location was an estimated 20 - 30 miles southeast of S.F. Bay Buoy-1. Your assignment is to conduct a SAR mission in the vicinity of Half Moon Bay. A lighthouse should be visible along with several navigational buoys as you make your down the coast. There will also be a platform buoy located in the immediate area. No course is provided for you at this point. Use your best judgement. **(Two-way communication is encouraged at this point.)**

To ensure you remain in good water, you need to once again transit the traffic separation scheme landward on a course of $054^0$ - $057^0$T. Upon reaching the final landward buoys, you will come to starboard and steer the necessary course to the reported SAR area. After locating the downed aircraft. There will be several buoys located landward off the port beam which will alert you to the location of hazardous waters.

Upon completing your SAR mission, you are when detached by the OTC are directed to steam independently into port. The latest weather report advises all vessels that the visibility has been reduced to approximately 10,000 meters outside the bay and even moreso within the bay. At this time, you will adjust your course to return to port and make the the safest speed possible. After steadying up on the new course, depress the FOG button on the control panel. This will turn fog on. Now set the range of visibility to 10,000 meters (which is all the way to the right).

You are to approach the two platform buoys from the seaward side of the channel and then come to a course which will allow for safe transit into the traffic separation scheme.

Remember, that you (DD) will now become the guide. The CG will take station astern of you and will proceed in port at a safe distance.

Comments:

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

## 5.4 TRANSITING A RESTRICTED WATERWAY(INBOUND)

This portion of the exercise requires that you return to port using the best course and safest speed possible. As you do so, you are to informed by the CG that she being senior intends to enter port ahead of you. Invariably you will come astern of her as the bothe of you return to port. Given the reduced visibility she will need to advise you of any course or speed changes made.

The course (or track for your return will not be provided during this portion of the exercise evaluation. You are to use your best judgement as to the course(s) of action necessary to pilot your formation safely through restricted waters.

Comments:

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### 5.4.1 Transiting a Traffic Separation Scheme (Inbound)

As you reach the two bouy platforms, adjust your course as necessary to ensure a seaward approach on them. Remember the CG should be ahead of you and headed inbound. Try to maintain visual range if possible. **(At this point in the exercise, both ships will be experiencing reduced visibility due to fog. You will have to communicate verbally to one another as you make your way into port)**.

Upon reaching the platform buoys, you are to come to a course and speed which will allow safe transit down the channel. You will make way between the two platforms and come to a course and speed that will allow the second vessel sufficient time to take station. Shortly after steadying up on your new course, you should notify the CG of the ordered base course and speed. While maintaining this course, you are encouraged to experiment with the various control panel features and comment on this portion of the exercise. **Remember that you will now be in a restricted manuevering status while steaming in formation**.

Comments:

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### 5.4.2 Manuevering While Steaming in Formation

Now that both ships are in their relative positions, continue to head into port. By the time you reach the Golden Gate Bridge, both ships should be in a column formation. Maintain a safe distance and speed until well within the channel. Manuever to anchorage located in the vicinity of the pier area. This concludes your portion of the exercise. If you desire, feel free to complete the remaining portion of the evaluation instrument before leaving or take it with you and return it to LCDR J.A. Nobles by way of the address on the envelope provided. If you desire, you may discuss your comments with the other participant at your leisure.

## 5.5 For CG-52 Platform

### 5.5.1 SHIPHANDLING IN RESTRICTED WATERS (Mooring to a Pier)

You are standing just outside the entrance to San Francisco Bay, approximately 4,000 yds West of the Golden Gate Bridge. Immediately astern of you are two seaward platform buoys. Your current heading is $070^{0}$T and you are lying-to, with no way on.

Your first task calls for getting underway and manuevering your ship alongside a pier (of your choice) located along the waterway. **(Due to the collision detection feature being on, you will only be able to approach the pier to within approximately 20 feet).**

The recommended course for entering port is $090^{0}$T. The recommended speed is 15 knots . As you clear the Golden Gate Bridge, immediately off your bow, you should see the first of two black buoys and a red-black band buoy off your starboard bouy. Using the most seaward black buoy, (turn bearing of 070 - 074) or the red-black buoy, (turn bearing

128 - 132) change course to 050 - 053$^0$T.  Remain on this leg until the inner most black buoy reaches a turn bearing of 105 - 110$^0$T, then change course to 090$^0$T.  This will keep you in  safe water.  Proceed with the previously assigned task of mooring alongside a pier (of your choice).

Once you are satified with your position, you may proceed to the next task.  **Remember to make mental and written notes regarding each task as you progress**.

Comments:

### 5.5.2  SHIPHANDLING IN RESTRICTED WATERS (Getting Underway from a Pier)

Now that you have successfully moored your vessel  alongside a pier (of your choice), prepare to get underway by clearing the mooring location and any harbor obstructions or traffic, then bring your ship fair for sortie in the harbor or departure channel.

It is the objective of this exercise to refamiliarize you with preparations for getting underway.  You will practice the use of various engine combinations,  the rudder, shooting bearings to stationary objects, and your basic instinct for safely handling your vessel as you sortie seaward through the restricted waterway.

The recommended course for exiting port is (for Leg1)  270$^0$T. Upon reaching a bearing of 229$^0$ - 235$^0$T on the first black buoy off your port bow, come left to course 252$^0$T. You will remain on this course for a while, which will place you on a course to the Golden Gate Bridge.

As you approach the second black buoy off your port bow, you will commence your next course change (for Leg2) to 243$^0$ - 246$^0$T.  The turn bearing for the second black buoy should be 207$^0$ - 212$^0$T.  Dead ahead you should see two platform buoy towers off the port and starboard bows respectively at approximately 10,000 - 14,000 yds.  Also you will notice several navigation aides off your port and starboard bows near land (green and red buoys) indicating the location of shoal water.  After clearing the bridge, you shall increase speed to either a FULL (20 knots) or FLANK BELL (30 knots).

Comments:

### 5.5.3 Transiting A Restricted Waterway (Outbound)

Upon clearing the Golden Gate Bridge, adjust your course to 248 - 252$^0$T (for Leg3). This will take you directly between the two buoy platforms leaving you with approximately 300 yards of good water off both the port and starboard beams. You may increase your transit speed to 30 knots if desired. This will significantly reduce your outbound transit time. The transit will take approximately 3 - 5 minutes.

During your transit, practice your use of the Azimuth Circle feature by taking bearings to various landmarks and navigational aides. You may want to experiment with several of the other controls featured on the panel. This might be a good time to jot down any comments or provide feedback on any components or features used thus far in the space provided below. **DO NOT MANIPULATE THE FOLLOWING CONTROL WIDGETS:** (1) Quit, (2) Playback, (3) Reset All, (4) Reposition, and (5) Save Screen.

Comments:

### 5.5.4 Transiting a Traffic Separation Scheme (Outbound)

As you reach the two buoy platforms, your fourth and final course (for Leg4) will take you through a 2,000 yard wide traffic separation scheme. Earlier during your seaward transit, you should have noticed several of its buoys as you were approaching the two seward platform buoys.

While traversing the channel, you will notice both red and black band buoys to port and green and black band buoys to starboard. Your turn bearings will be (to the port platform) 220 - 225$^0$T and (to the starboard platform) 278 - 285$^0$T. This new course should take you directly down the traffic separation scheme. Your final course should be approximately 232 - 234$^0$T. Shortly after steadying up on the new course, you should notice another platform bouy dead ahead bearing 233$^0$T. This is the S.F. Bay Buoy-1, the last platform bouy you will see when leaving port and the first upon your return to port.

While maintaining this course, you are encouraged to experiment with the various control panel features and to provide comments on this portion of the exercise.

Comments:

## 5.6 OPERATING IN COMPANY WITH ANOTHER VESSEL

**Note: You may or may not have the opportunity to work with the other vessel. In the event that you do not, proceed with the exercise as a single SAR unit.**

By the time you complete your transit of the traffic separation scheme, the second of the two vessels featured with system should have completed its manuevering in an open ocean exercises. Upon sighting it, you are to come about to either port or starboard, making a reciprocal course change to allow for a return transit back through the separation scheme. Upon rendezvousing with DD-976, you will assume tactical command and direct it take station astern of you at approximately 500 to 1,000 yards. Once both ships have completed the landward transit of the separation scheme, come right to a southerly course (South) toward Half Moon Bay.

As the OTC, direct the DD to proceed to take station on you, the Guide, in an optimal formation as you shall specify (i.e. astern, on the port/starboard beam, etc.). You will be involved in a Search and Rescue operation during this next phase of the exercise.

### 5.6.1 Conduct A Search and Rescue Operation

Adjust your time of day control to between 0.50 and 0.59. This should reduce the range of visibility and simulate night time operations. You will be operating in this environment for the remainder of the exercise.

The both ships will simulate receiving emergency S.O.S messages from an aircraft in distress. Its approximate location was an estimated 20 - 30 miles south east of S.F. Bay

Buoy-1. Your assignment is to conduct a SAR mission in the vicinity of Half Moon Bay. A lighthouse should be visible along with several navigational buoys as you make your down the coast.

To ensure you remain in good water, you need to once again transit the traffic separation scheme landward on a course of 054 - 057$^0$T. Upon reaching the final landward buoys, you will come to starboard and steer the necessary course to the reported SAR area. After locating the downed aircraft. Remember there will be several buoys located landward off the port beam which will alert you to the location of hazardous waters.

Upon completing your SAR mission, both ships receive a weather message warning all mariners in the immediate of rapidly closing fog and reduced visibility. You are to detach the DD and direct it to steam independently into port. However, since you are senior, inform the DD that you intend to enter port first.

As you depart, you will proceed westerly on a course (using maximum safe speed possible) that will take you back to the seaward entrance of the traffic separation scheme. Upon arrival to the area, you will come a safe course and speed for entering port. The DD will take station astern of you and proceed into port.

## 5.7 TRANSITING A RESTRICTED WATERWAY(INBOUND)

This portion of the exercise requires that you in company with the DD return to port using the best course and safest speed possible. As the guide, you are to inform the DD which is astern of you of any course and speed changes you might make so as to allow for proper station keeping on his part.

The course (or track for your return will not be provided during this portion of the exercise evaluation. You are to use your best judgement as to the course(s) of action necessary to pilot your formation safely through restricted waters.

Comments:

### 5.7.1 Transiting a Traffic Separation Scheme (Inbound)

As you reach the two bouy platforms, adjust your course as necessary to ensure a seaward approach on them. Remember the DD should be astern ofyou while entering port. Attempt to provide period course and speed changes as you make them so as to prevent collision. **(At this point in the exercise, both ships will be experiencing reduced visibility due to fog. You will have to communicate vocally to one another as you make your way into port)**.

Upon reaching the platform buoys, you receive the latest weather report which advises all vessels that the visibility has been reduced to approximately 10,000 meters just outside the bay and even moreso within the bay. At this time, you will adjust your course to the base course and notify the DD. After steadying up, depress the FOG button on the control panel. This will turn fog on. Now set the range of visibility to 10,000 meters (which is all the way to the right). By maintaining the ordered course and speed, you will allow for the DD to remain on base course and speed while returning to port. Remember, that the DD willastern of you. You will be returning to port in a column formation with the DD astern of you.

Comments:

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______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

### 5.7.2 Manuevering While Steaming in Formation

Now that both ships are in their assigned positions, your ship will be directed continue to practice safe shiphandling and piloting as you manuever into port. By the time you reach the Golden Gate Bridge, inform the DD that you will be going to anchorage near Alcatraz Island. Have the DD manuever to an anchorage near the piers within the inner harbor. Upon passing this directive, this will conclude your portion of the exercise. If you desire, feel free to complete the remaining portion of the evaluation instrument before leaving or take it with you and return it to LCDR J.A. Nobles by way of the EE/CS Curricilar Office (Room 407, Spanagel Hall), the Computer Science Department Office (Room 507, Spanagel Hall) or SGC Box 2108. If all else fells, just contact me at 373-4018 and I'll come an get it.

Once again thanks for your participation.

# APPENDIX D: USABILITY HEURISTICS ITEMS

The following is a list of the revised set of heuristics derived from a factor analysis of 249 usability problems. [NEIL94]

- **Visibility of System Status:** The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
- **Match Between System and the Real World:** The system should speak the users' language, with words, phrases, and concepts familiar to the user, rather than system-oriented terms, Follow real-world conventions, making information appear in a natural and logical order.
- **User Control and Freedom:** Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
- **Consistency and Standards:** Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
- **Error Prevention:** Even better than good error messages is a careful design which prevents a problem from occurring in the first place.
- **Recognition Rather Than Recall:** Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
- **Flexibility and Efficiency of Use:** Accelerators - unseen by the novice user - may often speed up the interaction for the expert user to such an extent that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
- **Aesthetic and Minimalist Design:** Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
- **Help Users Recognize, Diagnose, and Recover from Errors:** Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
- **Help and Documentation:** Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

## APPENDIX E: THE COGNITIVE WALKTHROUGH PROCESS

The following list offers an overview of the Cognitive Walkthrough Process used in the development of a effective usability study instrument.

1. **Define inputs to the walkthrough.**
   Identification of the users.
   Sample tasks for evaluation.
   Action sequences for completing the tasks.
   Description or implementation of the interface

2. **Convene the Analysis.**

3. **Walk through the action sequences for each tasks.**
   Tell a credible story, considering...
   Will the user try to achieve right effect?
   Will the user notice that the correct action is available?
   Will the user associate the correct action with the effect that user is trying to achieve?

4. **Record Critical Information**
   User knowledge requirements.
   Assumptions about the user population.
   Notes about side issues and design changes.
   The credible success story.

5. **Revise the Interface to Fix the Problems.**

# APPENDIX F: USER COMMENTS

This appendix contains a listing of the comments provided by the participants of the usability survey.

## A. General Comments:

- I felt this was a fairly accurate representation of a ship driving system. It was extraordinarily easy to understand and operate. Reaction of the ship to input seemed accurate, although the rudder seemed a bit slow while changes in speed seemed to occur a bit too quickly.
- Control of viewpoint very good. Controls were mostly intuitive. Instead of +/- for rudder control, should use left/right. Also, the indicators at the top of the screen showing rudder, speed, etc., should be in an instrument panel (maybe MOTIF). This would allow for easier sight of the indications regardless of the underlying terrain.
- Basically I feel that this is a good system, but to get effective training, a better physically based model(s) must be applied along with controls that closer approximate actual shipboard controls. An example of this is the ability to order a 1/3 bell vice using a slider.
- Excellent trainer!. The GUI was very intuitive and easy to ramp up on. Being a relative inexperienced computer person, I was able to handle the controls with no problems. Ship commands seemed very realistic to me. For example, overshooting a heading or new ordered course when using too much rudder. If you could somehow get some sound powered phones for comms, it would be excellent.
- I think I touch on the additional comments while going through the actual exercise. Basically I feel that this is a good system, but to get effective training, a better physically based model(s) must be applied along with controls that closer approach actual shipboard controls. An example of this is the ability to order a 1/3 bell vice using a slider widget.
- Sound effects would help significantly. I did not see any on-line help for using the azimuth circle. Water Depth is extremely necessary - particularly while in inland waters. Currents are a major factor inland/along side the pier. Should be added to the simulation. Controls are artificial, but their layout was ok for the simulation. To make this a much more real experience, voice recognition would help so that young JOs could practice their standard commands. However, for a Level-1 basic trainer, this is an excellent beginners tool.
- Survey is ridiculous long!
- The GUI was excellent; intuitive and consistent. The graphics were of high quality.

• The virtual environment was well conceived and implemented. As mentioned before, the ship does not drift enough with its acquired inertia when the shafts are stopped. This makes things like docking unrealistic.

• The inclusion of a chart of San Francisco Bay and surrounding waters with water deaths, would make the simulation more realistic. The fog was very nicely done. Obscuring of vision was done very realistically.

• Shipping density could be increased to add realism.

• Overall this was the best ship simulator I have ever used; very good shiphandling trainer; with added features would be an excellent deployable training device.

• I thought the simulation was very good for introductory shiphandling training. To increase the potential for more experienced or somewhat experienced shiphandlers, a physically based design or accurate modeling of speed, rudder, and course changes is imperative. the addition of currents would make this a mariners dream simulator.

• GUI was very good. Need an "ordered course to steer" function. As OOD I would frequently need to order a rudder angle (initial) and ordered course, then have to shift my attention to other critical things only occasionally checking on the helm to make sure he was getting me there. This feature is needed especially if you want to train OODs for more advanced tasks like air ops, unreps, battlestations/GQ. Being able to crash through buoys and platforms is an ok "training wheels" setup, but you need to stimulate the user to treat the system as if it were the real thing - some penalty or consequence for hitting ships/buoys etc.

• I thought the system was that when I decreased great with the exception of absence of surge and ranges. I noticed that when I decreased speed from 5 to 0 knots, I immediately stopped. There should be some surge involved. One thing that might be nice would be to have indications on the speed bars and rudder angles for standard changes (i.e. 5, 10, 15, degrees and 1/3, 2/3, Full, knots). This would make it easier to find standard engine and rudder orders.

• Having a fathometer would be nice.

• Ranges - needed from radar or lookouts for pierside, divtacs, etc.

• Chart - can't tell if on track -- need modified navy plot.

• Speed - Should have RPM to Speed Chart.

• View Control - very jumpy and hard to use precisely.

• Course - Cannot order a course -- have to devote too much attention to the feedback of the rudder indicator and control.

• Visuals - No Depth Perception. Hard to make out piers until too close.

• Rudder - Nothing to prevent high rudder at high speed or nothing to indicate roll effects -- don't want a conning officer to get used to using 20 degrees rudder at 30 knots.

• Comms - Use of S/P phones or equivalent would aid in enforcing proper comms between stations. This is important as trainee progresses to more advanced phases.

- I think you should put some fishing boats out there (with net lights and night light configurations IAW rules of the road). Wind and current effects are an important part of maneuvering. Ship should coast more after decreasing bell is rung up. There should be an anemometer for flight ops; in fact you ought to put ICONS for displays overhead so viewer can choose pertinent displays to evolution. When conditions should happen (i.e. lines go over, message displays). You could add a fading stern wake to help gauge maneuvering. Overall, a Superb Job. Hope my thesis is this useful.

- Need a radar or some indication of ranges. Especially when approaching a landing. A chart of the area is necessary in order to be familiar with where you're going and, more importantly, how to get back when the fog sits in. Need the ability to change settings using standard commands. Very important to JOs development. A time position printout that indicates rudder position and engine ordered would be great for critiquing pier approaches. Overall - Great way for JOs to get their feet wet!

- Would like to see a wake on moving ship's. Sound would also be more enhancing. (Gas turbine sound increasing pitch). Structure EOT similar to actual ship. Be able to take ranges of navaids and anything a surface search radar can pick-up.

- Great Simulation. Would like to see wind, set and drift effects added. The addition of a radar pop-up screens would assist the user in determine distances. The addition of other shipping would help tremendously. Visual effects (fog) are good. Water depth/danger bearings need to be added during piloting evolutions. How about a fathometer? Would like to see signal flags for comms between ships.

- Visual scenery was great. Need to add wind and current effects. More surface traffic and shipping would allow users to think and react to situations. Need some form of internal communications. The azimuth circle movement is very jerky, especially around the 000 degrees mark. Difficult to judge distances for mooring, station keeping.

Overall, a lot of real fun! Very good start as a JO trainer!

- Excellent concept/implementation. Fulfills a definite need. Simulator achieves desired "immersion effect". Felt like I was underway. Visual simulation models are very good.

# USER COMMENTS

## B. Comments Related to the Exercises

### 1. Mooring to a Pier

1. This (i.e. SAR Mission) was very easy to do. I liked the modeling used. All important buoys and land masses were easily spotted allowing for safe navigation.

2. The ship responded quite well. Seemed quite realistic...yet fun!

3. Need some information, other than jerking picture to indicate collision with other objects in the database. (Red lights, warning signs). Momentum is not modeled. Ship stops on a dime. Hard to control engines and throttles using analog input device. Better to select 1/3, 2/3, stop, Full, Flank.

4. Worked very well. Seemed realistic, yet fun.

5. Need some indication, other than jerking picture to indicate collision with dock. (Red light, warning signs). Momentum is not modeled. Ships stop on a dime. Hard to control pelorus and throttle using analog input device. Better to safely 1/3, 2/3, Standard, etc.)

6. Lack of drift is artificial and misleading. Learning when to take speed off or when and how much to back the engines. To slow/stop the ship is very important alongside. Ideally the simulator is the place that "feel" without hitting a real pick. This simulator gives the wrong impression that you can instantly stop the ship.

7. Rudder is very slow to respond - definitely not a DD-963 feel. Engine response good very good. (Must assume full plant. Future options should include various engine configuration and corresponding changes in ship response/limitations. For example, trail shaft is possible, but lock shaft, 4 engines on line - 2 shafts, 2 engines - 2 shafts, 2 engines - 2 shafts, 2 engines - 1 shaft, 1 engine - 1 shaft, etc.) Each of the above configurations results in very different ship performances.

8. Ship stops very fast, without backing down. Need wake.

### 2. Getting Underway from a Pier

1. Be nice to have a chart of the area. Always good to practice the ability to look at 2D chart and convert it into what it really looks like and vice versa. Analog input for viewing good, bad for shooting turn bearing.

2. Engine speed response is artificially fast. No, drift - this is very important and could actually be misleading to the trainee. Stopping engines does not stop the ship on a dime. This is not real world. The system needs to allow for drift.

3. Be nice to have a chart of the area. Always good to practice the ability to look at 2D chart an convert it into what it really looks like and vice versa. Analaog input for viewing good, bad for shooting turn by.

4. No standard RPMs or Engine Orders. Range to objects difficult to ascertain.

5. Speed change from 0 - 5 knots instantaneous!

6. Great twist ability, very realistic!

7. Soundings - Hard to see the pier. Building looks as if on shore. Don't have RPM to speed chart...had to guess.

8. View control very touchy.

9. Plot would be useful.

10. No range marks.

11. Causes you to think about all the things required for mooring.

12. How about adding tugs? Lets you think about where to place them.

### 3. Transiting a Restricted Waterway(Outbound)

1. Be nice to have a chart of the area. Always good to practice the ability to look at 2D chart and convert it into what it really looks like and vice versa. Analog input for viewing god, bad for shooting turn bearing.

2. As stated above, azimuth circle needs t be able controlled by a minimum of degree increments.

3. Viewpoint Control very good. Seemed accurate with respect to a real ship.

4. Screen features looked real good, once I got a feel of where everything was.

#### 4. Transiting a Traffic Separation Scheme (Outbound)

1. Buoys looked cool coming out of distant haze.

2. Sea state is similar to local Monterey - Pacific Grove area. Variable sea state could be a future modification.

3. As stated above, azimuth circle needs to be able to be controlled by a minimum of degree increments.

4. No penalty for high rudder at 30 knots.

5. How about a binocular view?

#### 5. Shiphandling in an Open Ocean(Performing Basic Shiphandling Maneuvers)

1. Ship did not pitch and roll in swells.

2. Williamson didn't seem to work might want to check numbers.

3. Do the ships have different turning rapids for different speeds.

4. Night time steaming appeared very realistic - very well done. Fog visibility also very good.

5. How about casualty control drills?

6. Needs proper shiphandling characteristics to be realistic.

#### 6. Formation Steaming (Conducting a Search and Rescue Mission)

1. The addition of ships wake would be a great help with depth perception.

2. Rudder delay or response is artificially long.

3. this was very easy to do. I liked the modeling used. All important buoys and land masses were easily spotted allowing for safe navigation.

4. No problems here. All functionality worked as advertised.

5. I thought this program was perfect for this type of training. Need to be able to get ranges to objects and other shipping.

6. Would have liked t have had a radar for this mission.

7. Wake, set and drift, etc. Would have been helpful.

### 7. Transiting a Restricted Waterway(Inbound)

1. No problems here. All functionality worked as advertised.

2. Multiple ships in company practicing formations w/manuevering boards would be an excellent training tool.

3. Need more obstacles for more experienced shipdrivers. Sailboats, smaller vessels, green peace, etc.

4. This is where the range feature would come in handy.

5. Difficult to “see” down the sides of the ship even from the bridge wings when mooring to the pier. Again the reality of surge would make this task more difficult and realistic.

### 8. Transiting a Traffic Separation Scheme(Inbound)

1. Went well. Easy to maneuver with other ship. Fog seemed quite accurate and realistic.

2. Need a button to switch from relative to true bearings.

3. Tide and current information needed for set and drift options.

4. Very difficult to get a precise bearing on a small object (buoy).

5. Need a nautical chart. Some kind of range information required to determine distance to other shipping.

### 9. Transiting During Reduced Visibility

1. Transiting A Traffic Separation Scheme(Outbound)

2. Need fog signals! We were just steaming along blind without radar.

# APPENDIX G: USABILITY STUDY DATA

This appendix contains in table form all of the data resulting from the Functionality Usability Survey. Questions selected for representation in these tables can be found in Appendix C.

| QUESTION | Number of Users Responding | | | | Percentage of Users Responding | | | | MEAN | MEDIAN | STD DEV | STD DEV OF MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | | | |
| 1 | 0 | 0 | 6 | 17 | 0 | 0 | 25 | 75 | 3.74 | .009 | .032 | .007 |
| 2 | 0 | 1 | 8 | 14 | 0 | 4 | 33 | 58 | 3.57 | .013 | .026 | .005 |
| 3 | 0 | 1 | 6 | 16 | 0 | 4 | 25 | 67 | 3.65 | .010 | .030 | .006 |
| 4 | 0 | 0 | 12 | 11 | 0 | 0 | 50 | 46 | 3.48 | .018 | .023 | .005 |
| 5 | 1 | 2 | 4 | 16 | 4 | 8 | 17 | 67 | 3.52 | .008 | .030 | .006 |
| 6 | 0 | 1 | 8 | 14 | 0 | 4 | 33 | 58 | 3.57 | .026 | .026 | .005 |

**Table G-1: Responses to Section 3.1**

| QUESTION | Number of Users Responding | | | | Percentage of Users Responding | | | | MEAN | MEDIAN | STD DEV | STD DEV OF MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | | | |
| 1 | 2 | 3 | 10 | 9 | 8 | 13 | 42 | 38 | 3.08 | .018 | .017 | .003 |
| 2 | 3 | 3 | 7 | 11 | 13 | 13 | 29 | 46 | 3.08 | .014 | .019 | .004 |
| 3 | 1 | 0 | 6 | 17 | 4 | 0 | 25 | 71 | 3.63 | .010 | .032 | .007 |
| 4 | 0 | 6 | 7 | 11 | 0 | 25 | 29 | 46 | 3.21 | .017 | .019 | .004 |
| 5 | 0 | 8 | 9 | 7 | 0 | 33 | 38 | 29 | 2.96 | .022 | .013 | .003 |
| 6 | 0 | 2 | 6 | 14 | 0 | 8 | 25 | 58 | 3.33 | .011 | .025 | .005 |
| 7 | 0 | 4 | 7 | 13 | 0 | 17 | 29 | 54 | 3.38 | .015 | .023 | .005 |

**Table G-2: Responses to Section 3.2**

| QUESTION | Number of Users Responding | | | | Percentage of Users Responding | | | | MEAN | MEDIAN | STD DEV | STD DEV OF MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | | | |
| 1 | 0 | 0 | 3 | 21 | 0 | 0 | 13 | 88 | 3.88 | .005 | .041 | .008 |
| 2 | 0 | 0 | 1 | 23 | 0 | 0 | 4 | 96 | 3.96 | .002 | .046 | .009 |
| 3 | 0 | 0 | 2 | 22 | 0 | 0 | 8 | 92 | 3.92 | .003 | .043 | .009 |
| 4 | 0 | 1 | 0 | 3 | 0 | 4 | 0 | 13 | 3.92 | .001 | .046 | .009 |
| 5 | 0 | 2 | 7 | 15 | 0 | 8 | 29 | 63 | 3.54 | .013 | .027 | .006 |

**Table G-3: Responses to Section 3.3**

| QUESTION | Number of Users Responding | | | | Percentage of Users Responding | | | | MEAN | MEDIAN | STD DEV | STD DEV OF MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | | | |
| 1 | 0 | 1 | 4 | 19 | 0 | 4 | 17 | 79 | 3.75 | .007 | .036 | .007 |
| 2 | 0 | 0 | 2 | 22 | 0 | 0 | 8 | 92 | 3.92 | .003 | .043 | .009 |
| 3 | 1 | 0 | 0 | 23 | 4 | 0 | 0 | 96 | 3.88 | .001 | .046 | .009 |
| 4 | 1 | 0 | 2 | 21 | 4 | 0 | 8 | 88 | 3.79 | .004 | .041 | .008 |
| 5 | 0 | 0 | 4 | 20 | 0 | 0 | 17 | 83 | 3.83 | .006 | .038 | .008 |
| 6 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 100 | 4.0 | .000 | .048 | .010 |
| 7 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 100 | 4.0 | .000 | .048 | .010 |
| 8 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 100 | 4.0 | .000 | .048 | .010 |
| 9 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 100 | 4.0 | .000 | .048 | .010 |

**Table G-4: Responses to Section 3.4**

| QUESTION | Number of Users Responding | | | | Percentage of Users Responding | | | | MEAN | MEDIAN | STD DEV | STD DEV OF MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | | | |
| 1 | 0 | 2 | 2 | 20 | 0 | 8 | 8 | 83 | 3.75 | .005 | .038 | .008 |
| 2 | 2 | 0 | 0 | 22 | 8 | 0 | 0 | 92 | 3.75 | .001 | .044 | .009 |
| 3 | 0 | 0 | 2 | 22 | 0 | 0 | 8 | 92 | 3.92 | .003 | .043 | .009 |
| 4 | 2 | 1 | 0 | 21 | 8 | 4 | 0 | 88 | 3.67 | .002 | .041 | .008 |
| 5 | 2 | 0 | 0 | 24 | 8 | 0 | 0 | 100 | 4.0 | .000 | .048 | .010 |
| 6 | 2 | 3 | 1 | 21 | 8 | 13 | 4 | 88 | 3.72 | .005 | .041 | .008 |
| 7 | 0 | 0 | 1 | 23 | 0 | 0 | 4 | 96 | 3.96 | .002 | .046 | .009 |
| 8 | 0 | 0 | 2 | 22 | 0 | 0 | 8 | 92 | 3.92 | .003 | .043 | .009 |
| 9 | 1 | 2 | 2 | 19 | 4 | 8 | 8 | 79 | 3.63 | .005 | .036 | .007 |

**Table G-5: Responses to Section 3.5**

| QUESTION | Number of Users Responding | | | | Percentage of Users Responding | | | | MEAN | MEDIAN | STD DEV | STD DEV OF MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | | | |
| 10 | 1 | 2 | 3 | 18 | 4 | 8 | 12 | 75 | 3.58 | .007 | .034 | .007 |
| 11 | 0 | 0 | 4 | 20 | 0 | 0 | 58 | 92 | 3.83 | .006 | .038 | .008 |
| 12 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 100 | 4.00 | .000 | .048 | .010 |

**Table G-5(Cont): Responses to Section 3.5**

# LIST OF REFERENCES


[AIRE90] Airey, John M., Brooks, Frederick P. Jr., and Rohlf, John H., "Towards Image Realism with Interactive Update Rates in Complex Virtual Building Environments," *Computer Graphics*, Vol 24, No 2, March 1990.

[BRUT94] Brutzman, Donald P., *A Virtual World for an Autonomous Underwater Vehicle*, Doctoral Dissertation, Naval Postgraduate School, Monterey, CA, 1994.

[CARD86] Card, Stuart K., Undersatnding Key Constraints Governing Human-Computer Interfaces, Xerox Palo Alto Reasearch Center, Palo Alto, CA, 1986.

[CREN77] Crenshaw, R. S., *Naval Shiphandling*, 1977. 4th Ed. Annapolis, Maryland: Naval Institute Press, 1977.

[DMA86] Defense Mapping Agency, *Product Specifications for Digital Terrain Elevation Data (DTED),* St Louis, MO. DMA Aerospace Center, 1986.

[FOSS94] Fossen, Thor I., *Guidance and Control of Ocean Vehicles.* New York: John Wiley & Sons Inc, 1994.

[GRIN93] Grinstein, George G., Breen, Paul T. and Cheng, Andrew. *Rapid Object Modeling for Interactive Design of Buildings*, Bedford, MA, The MITRE Corporation, 1993.

[IST93] Institute for Simulation and Training, *Standard for Information Technology - Protocols for Distributed Interactive Simulaton Applications (Draft),* Orlando, FL, 1993.

[JEPS93] Jepson, William, Ligget, Robin and Friedman, Scott, *Virtual Modeling of Urban Environments,* University of California, Los Angeles, CA, 1993.

[JONE94] Jones, Michael, "Lessons Learned from Visual Simulation", *Designing Real-Time Graphics for Entertainment,* SIGGRAPH, 1994.

[MALO85] Maloney, *Elbert S., Dutton's Navigation and Piloting*, Annapolis, MD, Naval Institute Press, 1985.

[MSI94] Marine Safety International, *U.S. Navy Simulator Shiphandling Training Student Guide*, Middletown, RI, 1993.

[NAS95] National Academy of Sciences, *Virtual Reality - Scientific and Technological Challenges,* National Academy Press, Washington, D.C., 1995.

[NIEL94] Nielsen, Jakob, Mack, Rlbert L., Usability Inspection Methods, New York: John Wiley & Sons Inc., 1994

[PRAT93] Pratt, David R., *A Characterization of Virtual World and Artificial Reality Systems*, Doctoral Dissertation, Naval Postgraduate School, Monterey, CA, 1993.

[SEAR79] Sears, Francis W., Zemansky, Mark W. and Young, Hugh D., *University Physics*, Addison-Wesley, 1979.

[SGIA94] Silicon Graphics Inc. Document Number 007-1680-020, *IRIS Performer Programming Guide*, J Hartman and P. Creek, 1994.

[SGIB94] Silicon Graphics Inc. Document Number 007-1681-020, *IRIS Performer Reference Pages,* S Fischler, J. Helman, M. Jones, J. Rohlf, A. Schaffer and C. Tanner, 1994.

[SHNE92] Shneiderman, Ben., *Designing the User Interface*, Addison-Wesley Publishing Co., Menlo Park, CA 1992

[USN94] U.S. Naval Regional Contracting Center, Washington Navy Yard, *Statement of Work to Contract N00600-91-R-1558 for services from Marine Safety International*, June 1993.

[ZYDA93] Zyda, M., Pratt, D., Falby, J., Barham, P., and Kelleher, K., “NPSNET and the Naval Postgraduate School Graphics and Video Laboratory,” *Presence*, Vol. 2, No. 3, 1993.

# BIBLIOGRAPHY


Basset, Frank E. and Smith, Richard A., editors. Farwell's Rules of the Nautical Road. 5th Ed. Annapolis, Maryland: Naval Institute Press, 1977.

Capitman, Barbara, American Trademark Designs. New York: Dover Publications, Inc., 1976.

Carse, Robert. Keepers of the Lighthouses. New York: Charles Scribner's Sons Press, 1969.

Crenshaw, R. S. Naval Shiphandling, 1977. 4th Ed. Annapolis, Maryland: Naval Institute Press, 1977.

Doherty, C.H. Bridges. New York: Meredith Press, 1969.

Fossen, Thor I., Guidance and Control of Ocean Vehicles. New York: John Wiley & Sons Inc., 1994.

Gibbs, Jim A. Lighthouses of the Pacific. West Chester: Schiffer Publishing Ltd., 1986. (ISBN 0-88740-054-X).

Harris, Dennis, Computer Graphics and Applications. London: Chapman and Hall Limited, 1984.

Holland, Francis R. America's Lighthouses: Their Illustrated History Since 1716. Brattleboro: Stephen Greene Press, 1972. (ISBN 0-8289-0148-1).

Hoefer, Hans J., San Francisco. 1st ed. Singapore: APA Publications, 1989.

Knopf, Alfred A. San Francisco USA. 1st ed. 1993 (ISBN 0-670-74913-6). Alfred A. Knopf, Inc.

Marine Safety International, U.S. Navy Simulator Shiphandling Training Student Guide, Middletown, RI, 1993.

McDowell, Jack. San Francisco: An Edited Pictorial. Menlo: Lane Publishing Co., 1977. (ISBN 0-376-05662-2).

Naval Regional Contracting Center, Washington Navy Yard, Statement of Work to Contract N00600-91-R-1558 for services from Marine Safety International, June 1993.

Neilsen, Jakob, Mack, Robert l., Usability Inspection Methods. New York: John Wiley and Sons, Inc., 1994.

Shanks, Ralph C. Lighthouses of San Francisco Bay. San Anselmo: Pacific Union College Press, 1976.

Shneiderman, Ben. Designing the User Interface. Addison-Wesley Publishing Company, Inc., 1993.

Starr, Kevin. San Francisco. New York: Rizzoli International Publications, Inc., 1990. (ISBN 0-08478-1243-x).

Sears, Francis W., Zemansky, Mark W. and Young, Hugh D., University Physics, Addison-Wesley, 1979.

Tate, William H., A Mariner's Guide to the Rules of the Road. Annapolis, Maryland: Naval Institute Press, 1976.

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